HILTOP Supplement

# HELIOCENTRIC INTERPLANETARY LOW THRUST
# TRAJECTORY OPTIMIZATION PROGRAM

Supplement # 1

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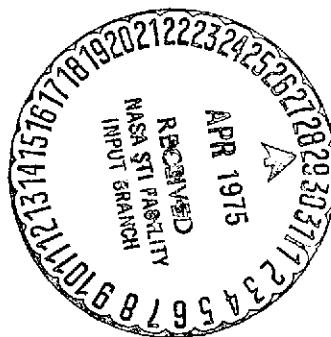J. L. Horsewood

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## SUMMARY

This report is the first supplement to the primary HILTOP program document published in January, 1973, and describes the modifications and improvements made to the HILTOP electric propulsion trajectory optimization computer program up through the end of 1974.

New program features include the simulation of power degradation, housekeeping power, launch asymptote declination optimization, and powered and unpowered ballistic multiple swingby missions with an optional deep space burn.

The report contains the new analysis describing these features, a complete description of program input quantities, and sample cases of computer output illustrating the new program capabilities.

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# I.    INTRODUCTION

This document describes the modifications and improvements made to
the HILTOP electric propulsion trajectory optimization computer program [1]
during calendar years 1973 and 1974. New program features include the simu-
lation of power degradation, housekeeping power, launch asymptote declination
optimization, and powered and unpowered ballistic multiple swingby missions
with an optional deep space burn.

The power degradation model has been hypothesized by the authors in
earlier publications [2, 3]. The model allows a single parameter (denoted
"characteristic degradation time") to describe the power degradation behavior
of an electric propulsion spacecraft to a degree which fundamentally affects
the solution to the trajectory optimization problem.

The option of simulating spacecraft housekeeping power applies to solar
electric propulsion with specified reference power. The housekeeping power
is a specified constant power generated by the solar arrays and shunted away
from the thruster power-conditioners and directly to the spacecraft payload
for "housekeeping" purposes.

The launch asymptote declination optimization model was first hypothesized
by the authors in the appendix of [1], and later a more thorough treatment of the
subject was put forth in [4]. A solution to the problem of optimizing electric
propulsion heliocentric trajectories, including the effects of geocentric launch
asymptote declination on launch vehicle performance capability, is developed
using variational calculus techniques. The model of the launch vehicle per-
formance includes a penalty associated with a non-easterly launch plus another
penalty arising from a non-coplanar launch from the parking orbit. Provisions
for range safety constraints are included. Optimal trajectories will generally
have the launch excess velocity offset from the initial primer vector.

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Extra-ecliptic mission simulations now involve launches from the Earth in which the Earth's ephemeris is generated by the program's analytic ephemeris capability; previously, extra-ecliptic missions were generated simply by starting the trajectory on the x-axis at one astronomical unit from the sun. This improved extra-ecliptic capability allows the launch date to be optimized together with the launch asymptote declination. Also, an additional set of boundary conditions has been added to the program for simulating extra-ecliptic missions.

The program's ability to simulate all-ballistic missions has been expanded to include powered and unpowered multiple swingby missions with an optional deep space burn. This capability renders HILTOP a powerful tool for ballistic mission design and optimization, with tremendous flexibility for creating imaginative multi-target mission profiles.

This report contains the analysis describing these new program features, a complete description of program input quantities, and sample cases of computer output illustrating the new program capabilities.

## II. FORMULATION

### A. SPACECRAFT AND TRAJECTORY MODELS

The assumed spacecraft and trajectory models are as described in [1] and are not repeated here; the nomenclature used in the following analysis is also described in [1], except for the introduction of new symbols which are described in the text as they appear.

1. Power Degradation. Historically, this electric propulsion power degradation model first appeared in the literature in [2], and then soon afterward an improved discussion appeared in [3], in which several of the ramifications and consequences of the theory are also discussed. For deeper insight into the analysis, the reader is therefore referred to [3], from which much of the analysis below is extracted.

The model discussed here is concerned with the manner in which the performance of a solar array degrades due to high energy particle damage. It is assumed that one can define a damage factor $q$ which has a value of unity at the initial time and which decreases in value with time during the course of the mission such that the power output, $p$, of the arrays at any time may be written

$$p = q \gamma p_{ref}$$

where $p_{ref}$ is the reference power and $\gamma$ is the power factor which is a function of solar distance and array orientation relative to the sun. The damage factor $q$ may also be thought of as a time-dependent efficiency. The derivative $\overset{\circ}{q}$ is negative, and is assumed to be linearly proportional to $q$ and to the density of particles impinging on the solar cells. For simplicity, it is assumed that the particle density $d$ is of the same form as the density of photons striking the surface of the array, i.e.,

$$d = \frac{\overline{e}_r \cdot \overline{n}}{r^2} \tag{1}$$

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where $\bar{e}_r$ is a unit vector along the sun-spacecraft line, $\bar{n}$ is a unit vector normal to the arrays such that $\bar{e}_r \cdot \bar{n} > 0$ implies the front of the panels faces the sun, and $r$ is the solar distance of the spacecraft. In the discussion to follow, an upper case symbol will denote a vector, a lower case symbol will denote a scalar, and a lower case symbol with a bar will denote a unit vector. Then

$$\overset{\circ}{q} = -kqd \tag{2}$$

and

$$q = e^{-k \int_0^t d\, dt'} \tag{3}$$

where $k$ is the constant of proportionality. It is convenient to introduce a parameter $s$, called degradation time,

$$s = \int_0^t d\, dt' \tag{4}$$

or

$$\overset{\circ}{s} = d \tag{5}$$

Thus, under the above assumptions the degradation time accumulates at a faster rate when the spacecraft is nearer the sun, which is a characteristic one might expect. Note that when the spacecraft is maintained at 1 AU with the panels normal to the sun line, $\overset{\circ}{s} = 1$ and the degradation time is equal to the flight time. Then $k$ may conveniently be thought of as the inverse of a reference time, called the characteristic degradation time denoted by $\tau_d$, and the degradation factor $q$ becomes

$$q = e^{-s/\tau_d} . \tag{6}$$

Actually, there is little reason to allow the degradation time $s$ to continue to accumulate during coast phases since the arrays may be turned edgewise to the sun and the degradation process may be effectively halted. Therefore, we adjust equation (5) to read

$$\overset{\circ}{s} = h_\sigma d \tag{7}$$

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where $h_\sigma$ is a step function equal to one during thrust phases and equal to zero during coast phases.

The characteristic degradation time $\tau_d$ is an engineering parameter that must be determined experimentally. For example, by exposing a solar cell to the particle emission of a solar simulator and measuring the performance of the cell over a period of time, one should be able to estimate a reasonable value of $\tau_d$. Another source of information would be measurements from actual spacecraft which employ solar cells for power supply.

The assumed exponential form of the degradation factor, although intended for use with SEP systems, is applicable for NEP systems as well. The principal difference is in the definition of $\dot{s}$; for example, $\dot{s} = h_\sigma$. The exponential form also permits one to evaluate radio-isotope systems by defining $\dot{s} = 1$ and letting $\tau_d$ represent the time for the radioactivity to dissipate to $1/e$ of its initial level.

In the development which follows, the formulation applicable to SEP is used exclusively. The equations of motion and adjoint equations are given in [1]; the equations affected by the inclusion of power degradation in the model are given below.

Power degradation affects the problem in a very fundamental sense, beginning with the rocket-thrust term in the equations of motion:

$$\dot{V} = \ddot{R} = a\, \bar{e}_t - \frac{\mu}{r^3} R$$

$$\dot{R} = V$$

(8)

where $R$ is the position vector, $r$ is the magnitude of $R$, $V$ is the velocity vector, $\mu$ is the gravitational constant of the sun, $a$ is the magnitude of the thrust acceleration and $\bar{e}_t$ is a unit vector in the direction of thrust. The thrust acceleration $a$ is a function of several variables and may be written as follows:

$$a = h_\sigma \frac{g\gamma q}{\nu}$$

where $g$ is a reference thrust acceleration evaluated under a prescribed set of conditions, $\nu$ is the ratio of current to initial mass, and $q$ is the degradation factor defined above. The power factor $\gamma$ is assumed to be a function of the density, $d$, of photons incident on the arrays, where $d$ is as written in equation (1). The general form of $\gamma$ is

$$\gamma = d \sum_{i=0}^{4} a_i d^{i/4} \qquad (9)$$

The coefficients $a_i$ are chosen so that this equation will adequately describe the power output of a given array. The only restriction on the $a_i$ is that their sum is equal to one. Then at $r = 1$ AU, with the arrays normal to the sun line, $\gamma = d = 1$. The summation term in (9) represents the temperature effect.

The mass ratio satisfies the differential equation

$$\dot{\nu} = - h_\sigma \frac{g\gamma q}{c} , \qquad (10)$$

using $\nu = 1$ as an initial condition, where $c$ is the jet exhaust speed which is assumed to be constant over the trajectory.

The variational Hamiltonian becomes

$$h_v = \Lambda \cdot \ddot{R} - \dot{\Lambda} \cdot \dot{R} + \lambda_\nu \dot{\nu} + \lambda_\tau \dot{\tau} + \lambda_s \dot{s} + \lambda_g \dot{g} + \lambda_c \dot{c}$$

$$= h_\sigma \left[ \frac{g\gamma q}{\nu} (\Lambda \cdot \bar{e}_t - \frac{\nu}{c} \lambda_\nu) + \lambda_s d + \lambda_\tau \right] - \frac{\mu}{r^3} (\Lambda \cdot R) - \dot{\Lambda} \cdot \dot{R} \qquad (11)$$

and the adjoint equations are

$$\ddot{\Lambda} = - \frac{\mu}{r^3} \Lambda + \frac{3\mu}{r^5} (R \cdot \Lambda) R + h_\sigma \left[ \frac{g\gamma^* q}{\nu} (\Lambda \cdot \bar{e}_t - \frac{\nu}{c} \lambda_\nu) + \lambda_s \right] \frac{\partial d}{\partial R}$$

$$\qquad (12)$$

$$\dot{\lambda}_\nu = h_\sigma \frac{g\gamma q}{\nu^2} (\Lambda \cdot \bar{e}_t)$$

$$\dot{\lambda}_g = -\dot{n}_\sigma \frac{\gamma q}{\nu} \left( \Lambda \cdot \bar{e}_t - \frac{\nu}{c} \lambda_\nu \right)$$

$$\dot{\lambda}_c = -h_\sigma \frac{g \gamma q}{c^2} \lambda_\nu \qquad\qquad (12)$$
$$(\text{cont.})$$

$$\dot{\lambda}_s = h_\sigma \frac{g \gamma q}{\nu \tau_d} \left( \Lambda \cdot \bar{e}_t - \frac{\nu}{c} \lambda_\nu \right)$$

where

$$\gamma^* = \partial \gamma / \partial d = \sum_{i=0}^{4} a_i \left( 1 + \frac{i}{4} \right) d^{i/4}$$

$$\frac{\partial d}{\partial R} = \frac{1}{r^3} \left[ \bar{n} - 3 (\bar{e}_r \cdot \bar{n}) \bar{e}_r \right]$$

The control variables are the thrust direction $\bar{e}_t$, the switch step function $h_\sigma$, and, providing the array orientation is not constrained to yield maximum power, the normal direction $\bar{n}$. According to the Maximum Principle, these controls are chosen to maximize the variational Hamiltonian (11). The maximum of $h_v$ with respect to $h_\sigma$ is seen to depend totally on the sign of the term in square brackets. That is, denoting

$$\sigma = \frac{g \gamma q}{\nu} \left( \Lambda \cdot \bar{e}_t - \frac{\nu}{c} \lambda_\nu \right) + \lambda_s d + \lambda_\tau \qquad\qquad (13)$$

then choose

$$h_\sigma = \begin{cases} 1 & \text{if } \sigma > 0 \\ 0 & \text{if } \sigma < 0 \end{cases} . \qquad\qquad (14)$$

Maximizing $h_v$ with respect to $\bar{e}_t$ is also accomplished by inspection. Since $\bar{e}_t$ appears only in the dot product with $\Lambda$ and since the coefficient of that dot product is non-negative, i.e.,

$$h_\sigma g \gamma q / \nu \geq 0$$

then $h_v$ is maximized with respect to $\bar{e}_t$ by making $\Lambda \cdot \bar{e}_t$ as large as possible,

which is the same result as when there is no degradation. The control vector $\bar{n}$ appears explicitly in (11) through the density $d$ as given by equation (1). In fact, since $\bar{n}$ only appears in $h_v$ through $d$, $\bar{n}$ only affects $h_v$ through its dot product with $\bar{e}_r$. Letting the angle between $\bar{n}$ and $\bar{e}_r$ be denoted $\chi$ such that $\bar{e}_r \cdot \bar{n} = \cos \chi$, then it is clear that there will be a "best" angle $\chi$ between $\bar{n}$ and $\bar{e}_r$ to maximize $h_v$, but that $\bar{n}$ may lie along any element of a right circular cone of half angle $\chi$ about $\bar{e}_r$. For the moment, we will put aside the question of the explicit direction of $\bar{n}$ and concentrate on defining the optimum $\chi$ or, alternatively, the optimum $d$. The optimum value of $d$ is determined by maximizing $h_v$ with respect to $d$, i.e., by solving for the root of the equation

$$\frac{\partial h_v}{\partial d} = h_\sigma \frac{\partial \sigma}{\partial d} = 0 \tag{15}$$

Performing the indicated differentiation yields

$$\frac{g \gamma^* q}{\nu} \sigma_r + \lambda_s = 0 \tag{16}$$

or

$$\gamma^* = - \frac{\lambda_s \nu}{g q \sigma_r} \tag{17}$$

where, using (9),

$$\gamma^* = \sum_{i=0}^{4} a_i (1 + \frac{i}{4}) d^{i/4} \tag{18}$$

and

$$\sigma_r = \Lambda \cdot \bar{e}_t - \frac{\nu}{c} \lambda_\nu$$

Because of the form of (18) equation (16) is a quartic in the variable $d^{i/4}$, and is solved by iteration in the program. A more detailed discussion of the solution to (16) is given in reference [3] for a specific set of coefficients $a_i$. For now, assume that the optimum value of $d$ is found from (16). Then the optimum angle $\chi$ is immediately obtained

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$$\cos \chi = d\, r^2 \tag{19}$$

Of course, equation (16) does not take into consideration the fact that $d$ can never exceed the inverse square of the solar distance. Consequently, the right hand side of (19) may exceed unity, under which condition the program sets $\cos \chi \equiv 1$ (i.e., $\chi = 0$) implying that $\bar{n}$ is directed along $\bar{e}_r$.

If the $d$ that represents the solution to (16) exceeds the upper limit allowed for $d$ whether that limit is imposed by the problem or by nature (i.e., $1/r^2$), the correct choice for $d$ is that upper-limiting value. Likewise, on the lower side, $d$ is physically limited to be non-negative. Therefore, a negative solution to (16) is disregarded, and $d$ is set to zero which corresponds to $\chi = \pi/2$ (panels oriented edgewise to the sun), and the engines are shut down.

The precise definition of $\bar{n}$ has no bearing on the solution of the problem, except as it affects $d$ as defined in (1). The appearance of $\bar{n}$ in the state and adjoint equations and the variational Hamiltonian is solely through the density $d$ except in the equation for $\ddot{\Lambda}$ where $\bar{n}$ appears explicitly as part of the partial $\partial d/\partial R$, defined following equations (12). Actually, this partial is valid only if $d$ is permitted to vary with $R$. That is, if either $d = 0$ or $d = $ constant is imposed then $\partial d/\partial R$ becomes the null vector and the entire term drops from the equation for $\ddot{\Lambda}$. Furthermore, if $d$ is the solution to (16), then the last term of $\ddot{\Lambda}$ in (12) again drops out because the term in square brackets is the left side of (16). Therefore, the only time the term in question remains in the equation for $\ddot{\Lambda}$ is when $d = 1/r^2$ which corresponds to $\cos \chi = \bar{e}_r \cdot \bar{n} = 1$ and implies $\bar{n} \equiv \bar{e}_r$. Under this condition

$$\frac{\partial d}{\partial R} = - \frac{2}{r^3} \bar{e}_r.$$

The boundary condition pertaining to the initial degradation time is

$$s(t_o) = 0$$

Although transversality conditions are discussed in the next section, the transversality condition associated with degradation time is stated here for the sake of completeness. If the final degradation time, $s_f$, is unspecified,

$$\lambda_{s_f} = 0 \ .$$

The initial value of $\lambda_s$ is unknown and therefore becomes one of the independent parameters of the boundary value problem. From equations (12), it follows that

$$\overset{\circ}{\lambda}_s = - \frac{g}{\tau_d} \overset{\circ}{\lambda}_g$$

and, therefore,

$$\lambda_{s_f} - \lambda_{s_o} = - \frac{g}{\tau_d} (\lambda_{g_f} - \lambda_{g_o})$$

Using the boundary conditions $\lambda_{s_f} = \lambda_{g_o} = 0$, it follows that

$$\lambda_{s_o} = \frac{g}{\tau_d} \lambda_{g_f} \ .$$

Thus, if an approximate value of $\lambda_{g_f}$ is available from a trajectory similar to the one of interest, a reasonable guess of $\lambda_{s_o}$ is readily available.

2. Housekeeping Power. This program option applies only to solar electric propulsion and is currently not integrated with the power degradation option. The program therefore does not allow the use of both options simultaneously. The new program input-quantity controlling the housekeeping power simulation is DPOW, which is the ratio of housekeeping power to reference power and is given the symbol $\Delta p$:

$$\Delta p = p_h / p_{ref}$$

The reference power $p_{ref}$ is defined as the power input to the power conditioners* under reference conditions. (For solar electric propulsion, reference conditions are equivalent to having the total spacecraft in a perfect solar-simulator such

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*When the thrusters are at full-throttle.

that the simulated solar distance is one astronomical unit, the solar arrays are oriented normal to the source of energy, and no radiation damage or other degradation effects have occurred to any components).

This spacecraft model assumes that the powers required by the operating components at each instant of time exactly match the power developed by the solar arrays:

$$p_a = p + p_h$$

where $p_a$ is the power developed by the arrays, $p$ is the instantaneous power delivered to the power conditioners, and $p_h$ is the housekeeping power, which is constant with time. Currently, all trajectories generated by the program using the housekeeping power simulation must satisfy the condition that $p_a > p_h$, so that $p$ remains positive; in other words, engine shutdown when $p \rightarrow 0$ is not coded into the program.

The power factor $\gamma$ is defined as the ratio of instantaneous power to reference power,

$$\gamma = p/p_{ref} = (1 + \Delta p) \sum_i a_i d^{(i+4)/4} - \Delta p$$

where the summation quantity $\Sigma$ is the power factor when $p_h = 0$.

The spacecraft model has been expanded by deleting the old, total propulsion system specific mass $\alpha$ and replacing it with $\alpha_a$, the specific mass of the solar arrays, and $\alpha_t$, the specific mass of the thruster subsystem. The quantity previously called the "propulsion system mass" is now expressed,

$$m_{ps} = \alpha_a p_{ao} + \alpha_t p_{ref} = (\alpha_t + \alpha_a (1 + \Delta p)) p_{ref}$$

where $p_{ao}$ is $p_a$ evaluated under reference conditions (i.e., $p_{ao} = p_{ref} + p_h$), and the total specific mass $\alpha$ has been replaced by $(\alpha_t + \alpha_a (1 + \Delta p))$, also a constant since the housekeeping power option is intended to be used only in

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simulations where the reference power is specified. The remainder of the analysis describing the optimization problem remains unchanged.

## B. BOUNDARY AND TRANSVERSALITY CONDITIONS

The basic boundary conditions and transversality conditions are described in [1]; the nomenclature used in the following analysis is also described in [1], except for the introduction of new symbols which are described in the text as they appear.

In summary, when no intermediate-targets are present, individual transversality conditions are derived from the general equation

$$d\pi + [\Lambda \cdot dV - \dot{\Lambda} \cdot dR + \lambda_\nu d\nu + \lambda_s ds + \lambda_\tau d\tau + \lambda_g dg + \lambda_c dc - h_v dt]_o^n = 0$$

where $\pi$ denotes the performance index which is assumed to be of the form

$$\pi = \pi (v_{\infty_o},\ v_{\infty_n},\ \nu_n,\ g,\ c,\ t_o,\ t_f)$$

such that

$$d\pi = \pi_{v_{\infty_o}} dv_{\infty_o} + \pi_{v_{\infty_n}} dv_{\infty_n} + \pi_{\nu_n} d\nu_n + \pi_g dg + \pi_c dc + \pi_{t_o} dt_o + \pi_{t_n} dt_n$$

where $\pi_x$ denotes $\partial\pi/\partial x$. The individual transversality conditions are obtained by equating to zero the coefficients of all independent differentials.

1. Deep Space Burn. In simulations of trajectories which are all-ballistic, the program is capable of simulating a single deep-space burn, or impulsive velocity-change, at any point prior to arrival at the primary target. The three components of the incremental velocity $\Delta V$ are independent variables of the boundary value problem, such that, at a specified time, the spacecraft velocity is incremented:

$$\dot{R}^+ = \dot{R}^- + \Delta V$$

The use of this program option is described in the Sample Problems and Results section under sample Case C, Multiple Ballistic Swingby Mission.

2. $V_\infty$ Optimization in LVI Mode. The optimization of the launch excess velocity $V_\infty$ when using the Launch Vehicle Independent (LVI) mode of simulation is accomplished when the initial primer vector is forced to vanish:

$$\Lambda_o = 0.$$

This is accomplished by setting the values of these three independent variables of the boundary value problem to zero and turning their triggers off; the three components of the departure heliocentric velocity become independent variables instead. The program contains special logic to circumvent the numerical singularity associated with the null primer vector.

3. Launch Asymptote Declination Optimization. This section contains the equations employed in the optimization of the launch asymptote declination. A more thorough exposition of this subject is found in [4], in which some of the ramifications of the theory are discussed. Historically, an incomplete form of this analysis was first published in the appendix of [1].

The assumed spacecraft and propulsion system models are as described in [1] and will not be repeated here. The launch vehicle payload capability is assumed to follow the simple exponential law

$$m_o = b_1 e^{-(v_c/b_2)} - b_3 , \tag{20}$$

where $b_1$, $b_2$, and $b_3$ are pre-determined constants for each launch vehicle and $v_c$ is a characteristic speed representative of the energy required to achieve a specific escape trajectory.

The velocity penalty incurred with non-due-East launches from the ETR is shown graphically in Reference [5] as a function of the parking orbit inclination. This velocity penalty $\Delta v_i$ is adequately approximated with a quadratic curve fit of the form

$$\Delta v_i = c_1 i^2 + c_2 i + c_3 \tag{21}$$

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Given a reference orbit inclination $i$ and a circular orbit speed $v_o$, the velocity penalty $\Delta v_g$ associated with a non-coplanar departure from this circular orbit to the desired hyperbolic excess velocity at a declination $\delta$ is defined as follows. Assuming the line of nodes of this reference orbit is an open variable, one may choose this variable to minimize the angle between the excess velocity and the orbital plane. This minimum angle is $\delta - i$. Gunther[6] has shown that the minimum incremental velocity required to achieve a given $v_\infty$ along an asymptote not lying in the orbital plane from a specified circular orbit is obtained from the solution to a quartic equation in the sine of the out-of-plane angle. Defining

$$s = \sin(\delta - i); \quad \rho = v_\infty / v_o \; ;$$

$$p = s^2 (\rho^2 + 4) \; ;$$

$$q = s^2 (1 - s^2) \rho^2 \; ;$$

$$x = \left[ \sqrt{(q/2)^2 + (p/3)^3} + q/2 \right]^{\frac{1}{3}} - \left[ \sqrt{(q/2)^2 + (p/3)^3} - q/2 \right]^{\frac{1}{3}} \; ;$$

$$y = \sqrt{\rho^2/4 - x} \; ; \tag{22}$$

$$w = \frac{1}{2} \left[ \rho/2 + y + \sqrt{(\rho/2 + y)^2 + 4 \left( x/2 + \sqrt{x^2/4 + s^2} \right)} \; \right] ,$$

then Gunther's solution for the magnitude of the minimum velocity impulse required to accomplish the maneuver is

$$v_g = v_o \sqrt{\rho^2 + 3 - 2 \sqrt{(1 + \rho w - w^2)(2 + \rho w)}} \; , \tag{23}$$

and the penalty $\Delta v_g$ is the difference between $v_g$ and the velocity increment required if the out-of-plane angle were zero, i.e.,

$$\Delta v_g = v_g - \left( \sqrt{v_\infty^2 + 2 v_o^2} - v_o \right) .$$

Thus, the definition of the characteristic speed for those cases in which the asymptote declination lies outside the interval $[-i, i]$ is

$$v_c = \sqrt{v_\infty^2 + 2v_o^2} + \Delta v_i + \Delta v_g$$

$$= v_o + v_g + \Delta v_i. \tag{24}$$

The transversality conditions which optimize the launch phase are developed as follows. The state and adjoint equations for the problem under consideration are precisely as formulated in [1]. The only difference in the optimality conditions is the format and content of certain of the transversality conditions. Specifically, these differences are due solely to the new definition of $v_c$ which is now a function of the direction of $V_\infty$ as well as its magnitude. Whereas before the differential of $v_c$ was, simply

$$dv_c = (v_\infty/v_c)\, dv_\infty,$$

it follows from (24) that the equivalent formula now is

$$dv_c = (\partial v_g/\partial v_\infty)\, dv_\infty + (\partial v_g/\partial \delta)\, d\delta$$

$$+ (\partial v_g/\partial i + \partial \Delta v_i/\partial i)\, di$$

where, from (21)

$$\partial \Delta v_i/\partial i = 2c_1 i + c_2,$$

and, from (22) and (23),

$$\partial v_g/\partial i = -\partial v_g/\partial \delta.$$

The derivation of the partial derivatives $\partial v_g/\partial v_\infty$ and $\partial v_g/\partial \delta$ is straightforward although somewhat cumbersome. The equations for these partial

derivatives are as follows:

$$\frac{\partial v_g}{\partial v_\infty} = \frac{v_o^2}{v_g}\left\{\rho\ \frac{\partial \rho}{\partial v_\infty} - \frac{w(3+2\rho w - w^2)(\partial \rho/\partial v_\infty) + (3\rho + 2\rho^2 w - 3\rho w^2 - 4w)(\partial w/\partial v_\infty)}{2\sqrt{(1+\rho w - w^2)(2+\rho w)}}\right\},$$

$$\frac{\partial v_g}{\partial \delta} = -\frac{v_o^2(3\rho + 2\rho^2 w - 3\rho w^2 - 4w)}{2v_g\sqrt{(1+\rho w - w^2)(2+\rho w)}}\ \frac{\partial w}{\partial \delta}\ ,$$

where

$$\partial \rho/\partial v_\infty = 1/v_o\ ,$$

$$\frac{\partial w}{\partial v_\infty} = \frac{1}{2}\left\{\frac{1}{2}\ \frac{\partial \rho}{\partial v_\infty} + \frac{\partial y}{\partial v_\infty} + \left[\left(1 + \frac{x}{2\sqrt{x^2/4 + s^2}}\right)\frac{\partial x}{\partial v_\infty} + \left(\frac{\rho}{2} + y\right)\left(\frac{1}{2}\ \frac{\partial \rho}{\partial v_\infty}\right.\right.$$

$$\left.\left. + \frac{\partial y}{\partial v_\infty}\right)\right]/(2w - \rho/2 - y)\right\}\ ,$$

$$\frac{\partial w}{\partial \delta} = \frac{1}{2}\left\{\frac{\partial y}{\partial \delta} + \left[\frac{\partial x}{\partial \delta} + \frac{x(\partial x/\partial \delta) + 4s(\partial s/\partial \delta)}{2\sqrt{x^2/4 + s^2}} + \left(\frac{\rho}{2} + y\right)\frac{\partial y}{\partial \delta}\right]/(2w - \rho/2 - y)\right\}\ ,$$

$$\partial s/\partial \delta = \cos(\delta - i),$$

$$\partial y/\partial v_\infty = \left[(\rho/2)\ \partial \rho/\partial v_\infty - \partial x/\partial v_\infty\right]/2y\ ,$$

$$\partial y/\partial \delta = -(\partial x/\partial \delta)/2y,$$

$$\frac{\partial x}{\partial u} = \frac{1}{6}\left[\frac{(q/2)(\partial q/\partial u) + (p/3)^2(\partial p/\partial u)}{\sqrt{(q/2)^2 + (p/3)^3}} + \frac{\partial q}{\partial u}\right]\left[\sqrt{(q/2)^2 + (p/3)^3} + q/2\right]^{-2/3}$$

$$-\frac{1}{6}\left[\frac{(q/2)(\partial q/\partial u) + (p/3)^2(\partial p/\partial u)}{\sqrt{(q/2)^2 + (p/3)^3}} - \frac{\partial q}{\partial u}\right]\left[\sqrt{(q/2)^2 + (p/3)^3} - q/2\right]^{-2/3}\ ,$$

with $u = v_\infty$ or $\delta$,

$$\partial q / \partial v_\infty = 2\rho s^2 (1 - s^2)(\partial \rho / \partial v_\infty) ,$$

$$\partial q / \partial \delta = 2\rho^2 s (1 - 2s^2)(\partial s / \partial \delta) ,$$

$$\partial p / \partial v_\infty = 2\rho s^2 (\partial \rho / \partial v_\infty),$$

$$\partial p / \partial \delta = 2s (\rho^2 + 4)(\partial s / \partial \delta).$$

This concludes the computation of these two partial derivatives. Some symbols used in this section of the document apply to this section only; for example, p and q here are intermediate quantities in the analysis, and have no relation to power or degradation factor discussed elsewhere.

The differential of g, the reference thrust acceleration, is

$$d g = - (g/m_o) \, d m_o$$

where

$$d m_o = - (b_1/b_2) e^{-(v_c/b_2)} d v_c ,$$

and the differential of $V_\infty$ may be written

$$d V_\infty = (V_\infty / v_\infty) \, d v_\infty + (\bar{n}_p \times V_\infty) \, d\alpha + [ (V_\infty \times \bar{n}_p) \times V_\infty / |V_\infty \times \bar{n}_p| ] \, d\delta ,$$

where $\bar{n}_p$ is a unit vector along the North Pole and $\alpha$ is the geocentric right ascension of $V_\infty$, and therefore the transversality conditions associated with $V_\infty$ are as follows:

For optimum launch parking orbit inclination:

$$f(\partial \Delta v_i / \partial i - \partial v_g / \partial \delta) = 0. \qquad (25)$$

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For optimum launch excess speed:

$$f(\partial v_g / \partial v_\infty) - (\Lambda_o \cdot V_\infty)/v_\infty = 0. \tag{26}$$

For optimum launch asymptote declination:

$$f(\partial v_g / \partial \delta) - \Lambda_o \cdot [(V_\infty \times \bar{n}_p) \times V_\infty / |V_\infty \times \bar{n}_p| ] = 0. \tag{27}$$

For optimum launch asymptote right ascension:

$$- \Lambda_o \cdot (\bar{n}_p \times V_\infty) = 0. \tag{28}$$

In the above equations $f$ is given by

$$f = [k_s + k_t - (1 + k_t) \nu_f - g \lambda_g / m_o] \, d m_o / d v_c$$

Due to the complexity of the equations defining $\partial v_g / \partial \delta$, the solution of equation (25) for the optimum value of $i$ must be obtained using an iterative technique.

The approach to the solution of the problem as formulated above differs in three basic respects from that of the problem where asymptote declination is ignored: (1) the condition (25) must be solved for the optimum parking orbit inclination, given values of $v_\infty$ and $\delta$; (2) the asymptote declination $\delta$ must be introduced as an independent parameter and (27) added as an end condition of the problem; and (3) the evaluation of $V_\infty$ becomes somewhat more involved. The computation of $V_\infty$ given $v_\infty$, $\Lambda_o$ and $\delta$, proceeds as follows: Denote as $\epsilon$ the obliquity of the ecliptic such that the matrix

$$\Phi = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \epsilon & -\sin \epsilon \\ 0 & \sin \epsilon & \cos \epsilon \end{bmatrix},$$

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operating on a vector expressed in ecliptic Cartesian coordinates yields the same vector in Earth equatorial coordinates. Then the right ascension $\alpha_\lambda$ of the initial primer $\Lambda_o$ may be written

$$\alpha_\lambda = \tan^{-1}\left[(\lambda_{yo}\cos\epsilon - \lambda_{zo}\sin\epsilon)/\lambda_{xo}\right],$$

where $\lambda_{xo}$, $\lambda_{yo}$, $\lambda_{zo}$ are the given ecliptic coordinates of $\Lambda_o$. Then, the right ascension of the asymptote is set

$$\alpha = \alpha_\lambda \quad \text{or} \quad \alpha = \alpha_\lambda + \pi,$$

and $V_\infty$ is evaluated

$$V_\infty = v_\infty \Phi^T \begin{bmatrix} \cos\alpha\cos\delta \\ \sin\alpha\cos\delta \\ \sin\delta \end{bmatrix}.$$

4. Extra-Ecliptic Missions. An additional set of boundary conditions has been added to the program for simulating extra-ecliptic missions.

The original set of boundary conditions is given on pp. 25-26 of reference [1], which is now invoked by employing the program input quantity IOUT = 1 and corresponds to i, e, and $r_p$ specified, $\Omega$ and $\omega$ optimized and f = 0, where i is inclination to the ecliptic, e is eccentricity, $r_p$ is perihelion distance, $\Omega$ is ascending node angle, $\omega$ is argument of perihelion, and f is true anomaly, all evaluated at the final time.

The new set of end conditions for extra-ecliptic missions is invoked by IOUT = 2 and is similar to the original set except that the final true anomaly is optimized rather than specified as zero, which corresponds to having the space-craft arrive at the optimum point of the extra-ecliptic orbit rather than being con-strained to arrive at perihelion. The specified final conditions are i, e, and a, where a is the final semi-major axis (in place of $r_p$). $\Omega$ and $\omega$ are optimized

as before, using the transversality conditions

$$T(\Omega) = \bar{k} \cdot C = 0 \tag{29}$$

$$T(\omega) = \bar{h} \cdot C = 0 \tag{30}$$

which are identical to equations (47) and (48) of reference [1]. $C = R \times \mathring{\Lambda} - \dot{R} \times \Lambda$ is the vector constant of the motion on a given trajectory segment, $\bar{h}$ is a unit vector along the angular momentum of the final orbit, and $\bar{k}$ is the z-axis unit vector. Optimizing f is accomplished by satisfying the transversality condition associated with f:

$$T(f) = \frac{\mu}{r} (\Lambda \cdot R) + r^2 (\mathring{\Lambda} \cdot \dot{R}) = 0 \tag{31}$$

The program attempts to satisfy equations (29), (30), and (31) directly, since no closed-form solution has yet been found for casting these end conditions in the form of $\Delta R$ and $\Delta \dot{R}$ similar to equations (54) and (55) of reference [1]. These end conditions possess poor convergence properties, a fact which the authors have experienced directly in attempting to obtain converged solutions using IOUT = 2.

5. <u>Multiple Target Missions - Errata</u>. Two equations in the section, Extension of Formulation for Multiple-Target Missions of reference [1] are in error. Equation (116) of reference [1] should read

$$\pi = j_r m_{rs} + m_o \left\{ k_s + k_t - (1 + k_t) \nu_n + j_r (1 + k_{rt}) e_x \left[ (1 + j_t k_t) \nu_n \right. \right.$$

$$\left. - j_t k_t (1 + \sum_{i=1}^{n-1} (k_{samp\,i} - k_{drop\,i})) \right] + (1 + k_t) \sum_{i=1}^{n-1} k_{samp\,i}$$

$$\left. - k_t \sum_{i=1}^{n-1} k_{drop\,i} \right\} + m_{ps} \left[ 1 - j_r j_{ps} (1 + k_{rt}) e_x \right]$$

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and equation (117) should read

$$\pi_{m_o} = \frac{\partial \pi}{\partial m_o} = k_s + k_t + j_p \frac{\alpha g c}{2\eta} - (1+k_t)\,\nu_n + (1+k_t)\sum_{i=1}^{n-1} k_{samp\,i}$$

$$- k_t \sum_{i=1}^{n-1} k_{drop\,i} + g_x \left[ (1+j_t k_t)\,\nu_n - j_t k_t \left(1 + \sum_{i=1}^{n-1} (k_{samp\,i} - k_{drop\,i}) \right) \right.$$

$$\left. - j_p j_{ps} \frac{\alpha g c}{2\eta} \; \right].$$

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## C. AUXILIARY COMPUTATIONS

This section presents equations employed in computations which are made after the iteration sequence involving the primary target is completed.

1. Additional Block Print Variables. A standard print block is employed for printing information at various points along a trajectory. Each standard block contains a total of forty parameters, which are described in [1].

The standard block may be augmented in two ways. When power degradation, as indicated by the input variable TPOWER, is simulated, a single line of information is automatically added to each block, as displayed in the Sample Problems and Results section, Case B, Comet Rendezvous Mission. When the input variable MPRINT is 2 or 3, three extra lines of information are generated per block, as displayed in the Sample Problems and Results section, Case C, Multiple Ballistic Swingby Mission. These two types of additionally printed lines may appear simultaneously.

(a). Power Degradation. The single line of power degradation information contains eight parameters as follows:

| | |
|---|---|
| S | Degradation time, s, since departure, in days, given by expression (4). |
| LS | Degradation time adjoint variable, $\lambda_s$. |
| DENSITY | Density parameter, d, used in expression (9) for the power ratio $\gamma$, and given by expression (1), in $AU^{-2}$. |
| DPOWR | $\partial \gamma / \partial r$, in $AU^{-1}$. |
| DPOWD | $\partial \gamma / \partial d$. |
| DEGRAD | The degradation factor, q, given by expression (6). |
| CHI | Solar array orientation angle $\chi$ as given by, for example, expression (19), in degrees. |

| CHI REF | Solar array orientation angle which the arrays would have if oriented for maximum power, in degrees. |

(b). Target-Relative Coordinates and Comet Magnitudes. The three extra lines which may appear via using MPRINT contain the following information:

| R1 REL<br>R2 REL<br>R3 REL | Cartesian components of current spacecraft position vector, with respect to the <u>next</u> astronomical body to be encountered along the trajectory in a moving coordinate system generated by that body, with the x-axis pointing outward along the body's heliocentric radius vector, the y-axis in the body's orbit plane in the direction of the body's motion, and the z-axis completing the right-handed orthogonal system, in kilometers, with the origin of coordinates at the body. |
| V1 REL<br>V2 REL<br>V3 REL | Cartesian components of current spacecraft velocity vector, in kilometers/second, in the target-relative coordinate system described directly above (see R1 REL). |
| RMAG REL | Magnitude of R1 REL, R2 REL, R3 REL, in kilometers. |
| VMAG REL | Magnitude of V1 REL, V2 REL, V3 REL, in kilometers/second. |
| S/C NUC MAG | Nuclear magnitude (of comet) of the next astronomical body to be encountered along the trajectory, as seen by the spacecraft. |

$$M_N = M_0 + M_1 \log_{10} |R - R_{targ}| + M_2 \log_{10} |R_{targ}|$$

$$+ .03 \cos^{-1} \left[ \frac{R_{targ} \cdot (R_{targ} - R)}{|R_{targ}| \ |R_{targ} - R|} \right] C^0$$

where $M_0$, $M_1$, and $M_2$ are magnitude constants
(Continued on next page)

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| S/C NUC MAG (continued) | associated with the target, and $C^o$ is the radians-to-degrees conversion factor. The arc-cosine term is the phase angle. |
|---|---|
| S/C TOT MAG | Total magnitude of the next astronomical body to be encountered along the trajectory, as seen by the spacecraft. |

$$M_T = M_3 + M_4 \log_{10} |R - R_{targ}| + M_5 \log_{10} |R_{targ}|$$

where $M_3$, $M_4$, and $M_5$ are magnitude constants associated with the target.

| GEO NUC MAG | Same as S/C NUC MAG, except as seen by the Earth. |
|---|---|
| GEO TOT MAG | Same as S/C TOT MAG, except as seen by the Earth. |
| ANG(V, R) | Angle which (V1 REL, V2 REL, V3 REL) makes with the positive x-axis in the target-relative coordinate system described under R1 REL, in degrees. |

$$ANG(V, R) = \cos^{-1} (V1\ REL/VMAG\ REL)$$

| ANG(V, XY) | Angle which (V1 REL, V2 REL, V3 REL) makes with the xy plane in the target-relative coordinate system described under R1 REL, in degrees. |
|---|---|

$$ANG(V, XY) = \sin^{-1} (V3\ REL/VMAG\ REL)$$

| R1 REL ECL<br>R2 REL ECL<br>R3 REL ECL | Same as R1 REL, R2 REL, R3 REL except expressed in the ecliptic coordinate system of date. |
|---|---|
| V1 REL ECL<br>V2 REL ECL<br>V3 REL ECL | Same as V1 REL, V2 REL, V3 REL except expressed in the ecliptic coordinate system of date. |
| RMAG ECL | Magnitude of R1 REL ECL, R2 REL ECL, R3 REL ECL, in kilometers. |
| VMAG ECL | Magnitude of V1 REL ECL, V2 REL ECL, V3 REL ECL, in kilometers/second. |

2. Swingby Continuation Analysis. Auxiliary computations are optionally provided, invoked by the NAMELIST input vector MOPT4, whereby ballistic swingbys past the primary target may be simulated.

In one mode of program operation, invoked by MOPT4(1) > 0, single swingbys past the primary target may be simulated to up to ten post-swingby targets per case.

In another mode of program operation, invoked by MOPT4(1) < 0, multiple swingbys along a single trajectory may be simulated, first swinging past the primary target and then subsequently swinging past more targets downstream along the trajectory. One multiple swingby trajectory may be simulated per case.

In either mode of operation, the following basic assumptions are made. The swingby continuation computations are independent of the trajectory leg leading up to the swingby target, which may consist of an optimized electric propulsion trajectory segment (if the swingby target is the primary target), except that the arrival $V_\infty$ and arrival time at the swingby target are used in the determination of the swingby passage conditions. Each swingby maneuver is calculated under the assumption of the patched-conic approximation, and the swingby planet's sphere-of-influence is assumed to have zero radius as seen from interplanetary space and infinite radius as seen from the planetary vantage point. The passage time in the swingby planet's sphere-of-influence is neglected (taken to be zero in the heliocentric frame).

Each swingby maneuver may be either unpowered or powered, and these two cases are discussed in the following sections. Since the unpowered swingby solutions are embedded in the wider class of powered-swingby solutions, tending to appear in pairs which are separated by a region of braking powered swingbys, the more general case of powered swingbys is discussed first.

(a). Powered Swingbys. This type of swingby maneuver is restricted to occur at the mutual perifoci of the approach and departure hyperbolic arcs; the powered phase is impulsive and the thrust is colinear (pro or con) to the velocity at closest approach. Whether the swingby is powered or unpowered, the trajectory segment leading up to the swingby planet has been pre-determined, this being the method by which the program has been designed to obtain swingby solutions. Therefore the swingby time and the arrival hyperbolic excess velocity $V_{\infty A}$ are known. In the following analysis, subscript A pertains to arrival at the swingby planet and subscript D pertains to departure.

A basic assumption of the powered swingby problem posed here is that the flight time from the swingby planet to the next target is specified. This being so, the program is able to converge, by iteration, on some ballistic trajectory from the swingby planet to the next target having the specified transfer time, implying that the departure hyperbolic excess velocity $V_{\infty D}$ at the swingby planet is thereby determined. Therefore, the heliocentric trajectory before and after the swingby planet is determined, and it then remains to perform the required computations pertaining to the hyperbolic arcs within the swingby planet's sphere of influence.

The closest approach distance is found by iteration as follows. Let

$$\alpha_A = 1 + \frac{r_p v_{\infty A}^2}{\mu}$$

and

$$\alpha_D = 1 + \frac{r_p v_{\infty D}^2}{\mu}$$

where $v_{\infty A} = |V_{\infty A}|$, $v_{\infty D} = |V_{\infty D}|$, $r_p$ is the (unknown) passage distance, and $\mu$ is the swingby planet's gravitational parameter. Then the approach and departure hyperbolic bend angles are given by

$$\frac{\delta_A}{2} = \operatorname{cosec}^{-1} \alpha_A = \sin^{-1} (1/\alpha_A)$$

$$\frac{\delta_D}{2} = \operatorname{cosec}^{-1} \alpha_D = \sin^{-1} (1/\alpha_D)$$

and these must sum up to the total bend angle, which is specified in terms of $V_{\infty A}$ and $V_{\infty D}$ :

$$\delta_T = \frac{\delta_A}{2} + \frac{\delta_D}{2} = \cos^{-1} \left[ \frac{V_{\infty A} \cdot V_{\infty D}}{v_{\infty A} \, v_{\infty D}} \right]$$

Therefore, using $r_p$ as the independent variable, the zero of the quantity

$$F = \sin^{-1} (1/\alpha_a) + \sin^{-1} (1/\alpha_D) - \cos^{-1} \left[ \frac{V_{\infty A} \cdot V_{\infty D}}{v_{\infty A} \, v_{\infty D}} \right]$$

is obtained by Newton's iteration, using the derivative

$$\frac{\partial F}{\partial r_p} = \left( \frac{-1}{\mu} \right) \left[ \frac{v_{\infty A}^2 / \alpha_A}{\sqrt{\alpha_A^2 - 1}} + \frac{v_{\infty D}^2 / \alpha_D}{\sqrt{\alpha_D^2 - 1}} \right]$$

When the iteration is converged, the passage distance $r_p$ is in hand, and the impulsive velocity increment is computed,

$$\Delta v = \sqrt{\frac{2\mu}{r_p} + v_{\infty D}^2} - \sqrt{\frac{2\mu}{r_p} + v_{\infty A}^2}$$

where the square-root-quantities are the hyperbolic speeds at closest approach. The remaining parameters defining the planetocentric transfer are computed as follows. The inclination of the swingby orbit plane to the planet's equator is given by

$$i = \cos^{-1} (\bar{h} \cdot \bar{n}_p)$$

where $\bar{h}$ is the unit vector along the angular momentum of the hyperbolic passage trajectory and $\bar{n}_p$ is a unit vector pointing toward the swingby planet's north pole.

The ascending node angle of the swingby orbit plane is computed as

$$\Omega = \tan^{-1} (-h_x / h_y)$$

and is placed in the proper quadrant by using the system library routine DATAN2. The argument of perifocus is given by

$$\omega = \cos^{-1} (\hat{r}_p \cdot \hat{r}_n)$$

where $\hat{r}_p$ is the unit vector pointing toward the closest approach point and $\hat{r}_n$ is the unit vector lying along the line of nodes and pointing toward the ascending node. This is adjusted for the proper quadrant by the test,

$$\text{If } h_z (\hat{r}_n \times \hat{r}_p)_z < 0, \qquad \omega \rightarrow 2\pi - \omega$$

In the right-handed planetary reference frame, the z-axis is toward the planet's north and the x-axis points toward the ascending node of the planet's equator on the ecliptic plane.

(b). Unpowered Swingbys. This type of swingby maneuver is considered to be a powered swingby having $\Delta v = 0$. The program adjusts the post-swingby heliocentric trajectory segment, by iteration, until the swingby departure $V_\infty$ magnitude equals the given arrival $V_\infty$ magnitude. The primary independent variable in this iteration is the post-swingby transfer time to the specified target, which was held constant in the powered swingby case. Thus $v_{\infty D} = v_{\infty A} = v_\infty$, and the swingby passage distance is obtained from the formula,

$$r_p = \frac{\mu}{v_\infty^2} \left( \frac{2 v_\infty}{|V_{\infty A} - V_{\infty D}|} - 1 \right)$$

The other orbital parameters are obtained from the same relations given above in the section, Powered Swingbys.

The program can generate multiple-revolution ballistic arcs, and a particular solution obtained by the program may not be unique, even for the same transfer time. All solutions are reachable, however, by means of inputting an appropriate initial velocity guess for the trajectory segment in question.

## III.  PROGRAM INPUT

The following consists of a <u>complete</u> description of program inputs. With respect to the basic HILTOP report [1], several input quantities have been added, some have been deleted, and some definitions have been modified. The input quantities which have been deleted are CALPHA, DIGIT, HALT, and WEIGHT, and so these names must no longer appear in NAMELIST MINPUT input data sets. CALPHA has been replaced by ALPHAA and ALPHAT. Also, $Y_i(4)$ and $Y_i(5)$ for $i = 1, 2, 3, \ldots, 70$ have been deleted (See the description of "dependent parameters" in the section just ahead, Definitions of Input Parameters) and should therefore also be removed from input data sets.

A.    NAMELIST

Inputs to HILTOP are given through the NAMELIST feature of the IBM Fortran IV programming language. The input NAMELIST is named MINPUT, and every input required or used in the program is declared by name in the list. The general form for assigning an input value to a quantity is, simply,

NAME = VALUE

where NAME is the name assigned to the variable and is included in the NAMELIST, and VALUE is a numerical or logical quantity consistent in form (i.e., logical, integer, or real) with NAME. Unless otherwise specified, all MINPUT names commencing with one of the letters I through N represent integers, whereas all names commencing with one of the letters A through H or O through Z are double precision floating point numbers. Each NAMELIST case must begin with the characters

&MINPUT

commencing in card column 2 and followed by at least one blank, and end with the characters

&END

preceded by at least one blank. Card column 1 is ignored on all NAMELIST input cards. Multiple data assignments on a single card are permissible if separated by commas. Blanks in the variable field, VALUE, are taken as zeroes. A comma following the last VALUE on a card is optional on the IBM system. The order of the input data assignments is arbitrary; i.e., they need not be in the same order as listed in the NAMELIST. In fact, there is no requirement that any specific input parameter be represented in the input data set. If no value is included in the inputs for a particular parameter, the default value is used (see Default Values). For other details regarding the NAMELIST feature, the reader is referred to the IBM System 360/Fortran IV

Language manual. NAMELIST cases may be stacked back-to-back indefinitely. A single NAMELIST error may wipe-out the remaining NAMELIST inputs.

B.    DEFINITIONS OF INPUT PARAMETERS

Specific examples of the program inputs are given in the Sample Problems and Results section. Default-values of inputs are given in the next section.

The program inputs, in alphabetical order, are:

AAI — Desired final extra-ecliptic inclination. Related to AE, AR, and IOUT. [deg]

AE — Desired final extra-ecliptic eccentricity. Related to AAI, AR, and IOUT.

ALPHAA — Specific mass of solar arrays, $\alpha_a$. [kg/kw]

ALPHAT — Specific mass of thruster subsystem, $\alpha_t$. [kg/kw]

ALTITU — This input variable is associated with program logic which has not been kept up-to-date, specifically, logic pertaining to optimum departure of a NERVA-type rocket from Earth orbit. This variable should be ignored.

AN — Trajectory-integration exponent in expression (37) of reference [1].

AR — Desired final extra-ecliptic perihelion distance. Related to AAI, AE, and IOUT. [AU]

ASOL — Array of five elements consisting of the solar power law coefficients $a_i$ in expression (17) of reference [1]. ASOL(1) > 0 tells the program to use the input coefficients rather than the internal coefficients. The coefficients are normalized internally, and the program executes the iterations to produce the required remarkable points of the power curve (which are printed).

BI — Efficiency coefficient b in expression (15) of reference [1]. Related to DI and EI.

B1
B2
B3 — Launch vehicle coefficients $b_1$, $b_2$, and $b_3$ in expression (2) of reference [1]. Used only if MBOOST is negative. [kg, m/sec, kg]

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| CNI | Inclination to ecliptic of primary-target orbit. Input only when MOPT3 = 11. Related to ECI, OMI, SAI, SOI, TPI, EMUODD, and RADODD. [deg] |
|---|---|
| CNIX | Array of five elements, the first three of which may be currently used. Inclinations to ecliptic of inter-mediate-target orbits. Input CNIX(i) only when MOPTX(i) = 11. Related to ECIX, OMIX, SAIX, SOIX, TPIX, EMUODX, and RADODX. [deg] |
| CSTR | Structural factor, $k_s$, in expression (7) of reference [1]. |
| CTANK | Propellant tankage factor, $k_t$, in expression (6) of reference [1]. |
| CTRET | Retro tankage factor, $k_{rt}$, in expression (10) of reference [1]. |
| DI | Efficiency coefficient d in expression (15) of reference [1]. Related to BI and EI. [km/sec] |
| DMRETR | Retro engine mass, $m_{rs}$, in expression (10) of reference [1]. [kg] |
| DPOW | Ratio of housekeeping power $p_h$ to reference power $p_{ref}$. The power transmitted to the propulsion system is that generated by the arrays less housekeeping power which is constant along the trajectory. The power output of the arrays normal to the sun at 1 AU is $p_{ref} + p_h$. |
| ECI | Eccentricity of primary-target orbit. Must be less than unity. Input only when MOPT3 = 11. Related to CNI, OMI, SAI, SOI, TPI, EMUODD, and RADODD. |
| ECIX | Array of five elements, the first three of which may be currently used. Eccentricities of intermediate-target orbits. Input ECIX(i) only when MOPTX(i) = 11. Related to CNIX, OMIX, SAIX, SOIX, TPIX, EMUODX, and RADODX. |
| EI | Efficiency coefficient e in expression (15) of reference [1]. Related to BI and DI. |

EMUODD        Gravitational constant of primary-target. Input only when MOPT3 = 11. Related to ECI, CNI, OMI, SAI, SOI, TPI, and RADODD. $[m^3/sec^2]$

EMUODX        Array of five elements pertaining to the gravitational constants of intermediate-targets. These inputs must be ignored at present.

GAMMAX        Maximum permissible value of the power function $\gamma$ when MODE = 5. At solar distances less than the value for which $\gamma$ = GAMMAX, the solar arrays are assumed to be tilted such that $\gamma$ is maintained at the limiting value.

GAP        Propulsion-corner proximity tolerance-interval, $\Delta\sigma$. See the discussion in the section Avoiding Corners in the Propulsion-time Function in reference [1]. Whenever the thrust switch function $\sigma$ grazes the zero-axis within the tolerance $|\Delta\sigma|$ on any trajectory, an internal counter is incremented, and the trajectory is considered to be in the neighborhood of a propulsion-time corner. Positive value of GAP causes forced-thrusting case to be inserted, negative value causes bypass to next case, whenever the internal counter reaches the related input variable NHUNG.

HOUR        Hour-of-day of reference date (e.g., 17.342D0). Related to MYEAR, MONTH, and MDAY.

IBAL        Ballistic option indicator. Setting IBAL $\neq$ 0 invokes option 1 discussed in the section Ballistic Trajectory Option of reference [1].

INTPR        Indicator which specifies print-length when the iteration in subroutine INTERP fails. Value of 0 causes short-print and 1 causes detailed-print.

IOUT        Extra-ecliptic mission indicator. IOUT = 1 or 2 indicates that extra-ecliptic target conditions are desired, in which the iterator dependent variable triggers Y1(2) through Y6(2) are set equal to 1, and for which the input LAUNCH (which see) should probably be set to 1, and parameters related to LAUNCH also set appropriately. Ordinarily MOPT2 = 3. No retro stage may be employed. (Continued on next page).

| IOUT | $= 1$ | $i$, $e$, $r_p$ specified; $f = 0$. |
| (cont) | $= 2$ | $i$, $e$, $a$ specified; $f$ optimized. |

In the above, $i$ = final extra-ecliptic inclination, $e$ = final eccentricity, $r_p$ = final perihelion distance, $a$ = final semi-major axis, and $f$ = true anomaly at the final time. Final $\Omega$ and $\omega$ are optimized in both cases. Related to AE, AR, and AAI.

IRK       Numerical integration option (currently not used).

IRL       Primer-origin-proximity step-size-control indicator. Value of zero causes bypass of control, leaving the step-size $\Delta u$ constant. See discussion in the section, Integration (Thrust) of reference [1].

IROT       A non-zero value of IROT causes the input ecliptic projection of the primer vector and its time derivative to be rotated about the z-axis through an angle equal to the difference in longitudes of the spacecraft between the last trajectory of the previous case (or zero if no previous case) and the first trajectory of the current case. This feature permits one to use the initial adjoint variables from a 2-dimensional trajectory as the initial-guess inputs for a 3-dimensional trajectory using the ephemeris option. IROT must be set back to zero to avoid undesirable rotations on subsequent cases.

ISPIN       Spinner indicator. Not used at present.

ITF       Provides normal termination conditions for runs which require more machine time than is estimated. The value specifies the number of machine-time seconds (CPU and I/O) required to execute the summary trajectory after halting the iteration-sequence. [sec] Does not apply if subroutine REMTIM is dummied.

ITPRNT       Indicator for special print from MINMX3 iterator. Non-zero value invokes print.

JPP       Jettison indicator $j_{ps}$ for electric propulsion system prior to primary-target retro-maneuver, as used in expression (8) of reference [1]. (Continued on next page).

| JPP (cont) | = 0 Propulsion system not jettisoned |
| | = 1 Propulsion system jettisoned prior to retro maneuver. |

JPRINT      Unit 11 printout-length indicator. A value of zero causes the iterator independent and dependent variables to be output only for each summary-trajectory; a value of one causes the same output additionally at each iteration of an iteration-sequence.

JT      Jettison indicator $j_t$ for electric propulsion tankage prior to primary-target retro-maneuver, as used in expression (8) of reference [1].

         = 0 Tankage not jettisoned
         = 1 Tankage jettisoned prior to retro-maneuver.

KPART      Option for automatically selecting improved independent parameter perturbations for generating the iterator's partial derivative matrix. The option is invoked by setting KPART = N (N > 0), where N is the maximum number of allowed steps, as discussed in the section, Perturbation Step Size Selector of reference [1]. KPART must be set back to zero if not desired on subsequent cases.

LAUNCH      Launch mode selector, pertaining to the optimization of the departure asymptote declination, invoked by LAUNCH = 1. Related to X10, Y10, X17, and Y17.

LOADX      Intermediate-target initial-guess feature. Should be used with NSET(5) = 1, and then set to zero on the subsequent case. A non-zero value of LOADX will invoke this feature, whereby the primer $\Lambda$ and its derivative $\dot{\Lambda}$ will be loaded into the iterator independent-variable arrays at each intermediate-target (Continued on next page).

LOADX
(cont)
provided that the trigger of the independent variable
is on. The sole purpose of this capability is merely
to generate an initial-guess for a multiple-target
mission, where the values loaded into the iterator
arrays represent continuous $\Lambda$ and $\dot\Lambda$ at each target.

MAXHAM
Maximum number of times that the program will print
the warning message BAD HAMILTONIAN on any given
computer run.

MBOOST
Launch vehicle selector.

|  |  |
|---|---|
| = 0 | ATLAS (SLV3X)/CENTAUR |
| 1 | TITAN III C |
| 2 | TITAN III C (1207) |
| 3 | TITAN III X/CENTAUR |
| 4 | TITAN III X (1207) |
| 5 | TITAN III X (1207)/CENTAUR |
| 6 | SATURN IB/LM |
| 7 | SATURN IB/CENTAUR |
| 8 | SATURN IC/SIVB/CENTAUR |
| 9 | TITAN III X (1205)/CENTAUR |
| 10 | TITAN III B (CORE)/CENTAUR |
| 11 | TITAN III D (1205)/CENTAUR |
| 12 | DELTA |
| 13 | TITAN III D |
| 14 | TITAN III D (1205)/CENTAUR/TE364 (2250) |
| 15 | TITAN III E/CENTAUR |
| 16 | SHUTTLE/TRANSTAGE |
| 17 | SHUTTLE/DELTA |
| 18 | SHUTTLE/AGENA |
| 19 | SHUTTLE/CENTAUR |
| 20 | SHUTTLE/CENTAUR/BURNER II (2300) |
| NEG | Use input booster coefficients $b_1$, $b_2$, and $b_3$. |

MDAY
Day-of-month of reference date (e.g., 26). Related to
MYEAR, MONTH and HOUR.

MODE
Power variation option selector. The value of MODE is
equal to the option-number of the power-curve, discussed
in the section, Electric Propulsion System of reference
[1] (which see). Possibly related to ASOL and GAMMAX.
MODE = 1 has been eliminated.

MONTH
Month-of-year of reference date (e.g., 8). Related to
MYEAR, MDAY, and HOUR.

MOPT       Ballistic option indicator. Using MOPT invokes option 2, discussed in the section, Ballistic Trajectory Option, of reference [1], as follows:

   = 0  No action (use input $\Lambda_o$, $\dot{\Lambda}_o$, and $v_{\infty o}$).

   = 1  Generate ballistic solution with flyby end conditions.

   = 2  Generate ballistic solution with orbiter end conditions.

Related to REVS.

MOPTX      Array of five elements, the first three of which may be currently used. This array specifies the target-number, or planet-number, of the successive intermediate-targets, and a value of zero indicates absence of the intermediate-target. A zero-entry must not precede a non-zero entry. Planet selection is the same as for MOPT2. MOPTX(1) pertains to iterator parameters X41-X50 and Y41-Y50; MOPTX(2) pertains to X51-X60 and Y51-Y60; and MOPTX(3) pertains to X61-X70 and Y61-Y70. Times at the targets are X48, X58, and X68. Not to be used unless MOPT2 $\neq$ 0.

MOPT2      Launch planet number and ephemeris-option indicator.

   = 0  Analytical planetary ephemeris is not used.

   $\neq$ 0  Analytical planetary ephemeris is used and the specific launch planet is selected as follows: (Continued on next page).

| | | | |
|---|---|---|---|
| = 1 | Mercury | = 14 | Icarus (1978)* |
| 2 | Venus | 15 | Eros |
| 3 | Earth | 16 | Geographos (1983)* |
| 4 | Mars | 17 | Encke (1977)* |
| 5 | Jupiter | 18 | Encke (1984)* |
| 6 | Saturn | 19 | Encke (1987)* |
| 7 | Uranus | 20 | Halley |
| 8 | Neptune | 21 | Betulia |
| 9 | Pluto | 22 | Toro (1983)* |
| 10 | Ceres | 23 | Pallas |
| 11 | Input Target** | 24 | Juno |
| 12 | D'Arrest (1982)* | 25 | Vesta |
| 13 | Encke (1980)* | 26 | Astraea |

*Year-value indicates apparition for which internal orbital elements are most accurate.

**Input corresponding orbital elements (see CNI, CNIX). None are available for the launch planet.

MOPT2          = 27  Hebe
(cont)           28  Iris
                 29  Flora
                 30  Achilles
                 31. Amor
                 32  Hidalgo
                 33  Alinda
                 34  Grigg-Skjellerup (1977)*
                 35  Kopff
                 36  Grigg-Skjellerup (1982)*
                 37  Ganymed
                 38  Ivar
                 39  Beira
                 40  Kepler
                 41  Giacobini-Zinner (1985)*
                 42  Borrelly (1987)*
                 43  Tempel II (1988)*
                 44  Tempel II (1983)*
                 45  Tuttle-Giacobini-Kresak
                 46  Schaumasse
                 47  Honda-Mrkos-Pajdusakova
                 48  Giacobini-Zinner (1979)*
                 49  Icarus (1987)*
                 50  Toro (1987)*
                 51  Geographos (1987)*

*Year-value indicates apparition for which internal orbital elements are
  most accurate.


MOPT3          Planet number of primary-target.  Planet selection is the
               same as for MOPT2.  If ephemeris is not used, MOPT3
               is used only for retro-stage mass computations.

MOPT4          Array of ten elements, specifying up to ten post-swingby
               targets.  Planet selection is the same as for MOPT2, and
               a value of zero indicates the absence of a post-swingby
               target.  A negative value in MOPT4(1) selects multiple
               ballistic swingbys, rather than a set of single swingbys
               in which case also set MAXHAM = 0.  Negative values
               (in absolute value) produce planet selection the same as
               for MOPT2.  When MOPT4(1) < 0, the remaining elements
               of MOPT4(i) may be positive or negative.  See the section,
               Swingby Continuation Analysis for details and Sample Case
               C for an example-case.  Should be used only for primary-
               target flyby missions.  Related to T2, MSWING, NSWING
               and XSWING.

MPOW      Flag used in conjunction with the solar array degradation option. Value of zero results in the optimum orientation of the arrays relative to the sun line. A non-zero value forces the arrays to an orientation yielding the maximum power achievable at that instant. Related to TPOWER.

MPRINT      Indicator for printing the summary-trajectory (final trajectory of a case) as a function of time or for invoking extra printout.

     = 0   Small-size block print at thrust switch points only (SWITCH POINT SUMMARY page).

     = 1   Same as = 0, except expands to become a standard print-block of parameters for each computed point along the trajectory, including the trajectory extension controlled by the input variable TGO.

     = 2   Same as = 0, except each block contains extra lines consisting of target-relative coordinates and target magnitudes.

     = 3   Combination of =1 and =2.

MPUNCH      Punched-card and trajectory-tape generation control.

     = 0   No special output.

     1   Punch final values of independent parameters.

     2   In addition, punch selected mission analysis parameters used for graphic documentation or other purposes.

  < 0 and > -100   Punch trajectory output used with the ASTEA program. The absolute value of MPUNCH determines the frequency of trajectory points output.

     ≤ -101   Trajectory tape output used with the ASTEA program. The absolute value less 100 determines the frequency of trajectory points output. Related to NTAPE.

MREAD          Card input option (iterator independent variables)

          = 0  No special cards input.

            1  The independent variables generated by
              a previous run by the MPUNCH option are
              input following the NAMELIST case, as
              discussed in the section, Program Output,
              of reference [1].

MSWING         Array of ten elements, used only when running multiple-
              target ballistic swingbys, such that MSWING(i) corres-
              ponds to MOPT4(i) and selects the type of swingby
              maneuver desired at the respective swingby target.
              Used only if MOPT4(1) < 0.  The shooting method
              (MINMX3 iterator) is used, and values of  -1, -2, or
              -3  correspond to a swingby passage distance initial
              guess of  $r_p = \infty$  (i.e., continuous heliocentric velocity).
              Each element MSWING(i) may have any of the following
              values:

          = - 1  Go* directly for unpowered swingby; if and
                only if it fails, go for powered swingby having
                flight time T2(i) = initial guess.

          = - 2  Go directly for powered swingby <u>only,</u> having
                T2(i) = flight time, of post-swingby leg.

          = - 3  Go directly for unpowered swingby; then,
                whether it succeeds or not, go for powered
                swingby having T2(i) = flight time.

          = - 4  Go directly for unpowered swingby, but
                using initial velocity guess loaded into
                XSWING(j, i), j = 1, 2, 3, similar to
                MSWING(i) = - 1.

          = - 5  Same as = - 2, except use initial guess as
                in = - 4.

        *"Go for" means "attempt to obtain (solution)".
        Related to MOPT4, T2, XSWING, and NSWING.

MTMASS         Mission-type selector pertaining to the primary target.

          = 0  Flyby mission

             1  Orbiter (high-thrust retro-maneuver without
                velocity loss).

      (Continued on next page).

MTMASS  
(cont)

= 2 Orbiter (high-thrust retro-maneuver with velocity loss).

3 Specified arrival excess speed $v_{\infty n}$.

If $v_{\infty n} = 0$, rendezvous mission

If $v_{\infty n} > 0$, controlled flyby mission

No retro-maneuver in either case.

4 Orbiter (Electric propulsion system performs spiral maneuver. Arrival excess speed $v_{\infty n}$ must be specified as zero).

Other parameters which may be related to MTMASS are DMRETR, CTRET, RPER, RAP, THRET, SPIRET, JPP, and JT.

MUPDAT

Flag indicating whether iterator independent variables at end of one case are to be used as first guesses for next case.

= 0 Use input initial guesses.

1 Use independent variables of previous case as first guesses.

MYEAR

Year of reference date (e.g., 1982). Related to MONTH, MDAY, and HOUR.

NDIST

Identification number of celestial body to be used as the reference for the communication distance and angle measurement printed in the Extremum Point Summary Table. Identification code is the same as for MOPT2.

NHUNG

Maximum number of propulsion-corner-proximity occurrences allowed in a given iteration-sequence. Related to GAP.

NORMAL

Automatic adjoint-variable scaling.

= 0 No action.

1 All $\Lambda$ and $\dot{\Lambda}$ are scaled such that $\lambda_{\nu o}$ becomes unity.

NPERF          Identification number of end condition that is to be used as the performance index when employing the direct parameter optimization feature (Improve Mode). The identification code is the same as the i in the Yi end condition array.

NPRINT         Print selection flag. Permits selection of amount of printout desired on each case.

                    = 0  Print only the case summary.

                      1  Print switching point summary of final trajectory.

                      2  Print MINPUT and case setup.

                      4  Print trajectory summary on each iteration.

                      8  Print partial derivative matrix each iteration.

               Combinations of options obtained by summing options desired. If NPRINT > 15, printout consistent with NPRINT = 0 is obtained. If the sign of NPRINT is reversed to negative, the iterator independent and dependent variables additionally are printed for every trajectory which HILTOP generates (including neighboring trajectories).

NSET           Iteration-sequence control array.

               NSET(1)     Not used for input.

               NSET(2)     Not used for input.

               NSET(3)     Maximum number of iterations permitted in attempting to satisfy (point) constraints in satisfy mode. If zero, no upper limit imposed.

               NSET(4)     Flag indicating whether (point) constraints are to be satisfied prior to entering improve mode.

                              = 0  Satisfy constraints first.

                                1  Proceed immediately to improve mode.

               NSET(5)     Maximum number of iterations permitted after entering improve mode. Setting NSET(5) = 1 causes iterator to be bypassed and computes single trajectory to obtain printout.

45

NSWING      Swingby continuation analysis option indicator. When
            zero or positive, NSWING is the number of full revolutions
            which the post-swingby heliocentric trajectory must have,
            and subroutine ACONIC (not MINMX3) is used to obtain the
            solution. When negative, NSWING has the same definition
            as MSWING (which see), and the MINMX3 iterator is used;
            NSWING must be used when MOPT4(1) > 0, and may be
            used when MOPT4(1) < 0. If MOPT4(1) < 0 and MSWING(i)
            = 0, then MSWING(i) will be set to the value of NSWING.
            Related to MSWING, MOPT4 and T2.

NSWPAR      Iterator independent-variable perturbation-increment
            control.

                 = 0  No action.

                   1  Allows the iterator to vary a given in-
                      dependent-variable perturbation $\Delta x$
                      whenever a neighboring trajectory is
                      detected which has a different number
                      of thrust switch points than the associated
                      nominal trajectory. $\Delta x$ is varied until
                      the same number of switch points is
                      achieved.

NTAPE       Specifies the unit-number for the trajectory tape.
            Pertains to when MPUNCH $\leq$ – 101.

OMI         Ascending node angle (with respect to vernal equinox)
            of primary-target orbit. Input only when MOPT3 = 11.
            Related to CNI, ECI, SAI, SOI, TPI, EMUODD, and
            RADODD. [deg]

OMIX        Array of five elements, the first three of which may
            be currently used. Ascending node angles of inter-
            mediate-target orbits. Input OMIX(i) only when
            MOPTX(i) = 11. Related to CNIX, ECIX, SAIX,
            SOIX, TPIX, EMUODX, and RADODX. [deg]

POWFIX      Launch-vehicle-independent (i.e., no launch vehicle)
            trajectory option in which the value of POWFIX is the
            spacecraft's reference power. [kw]

PSIGN
Flag defining the sense of the launch hyperbolic excess velocity relative to the initial primer vector. A value of +1. results in the assignment of the geocentric right ascension of the excess velocity equal to that of the initial primer vector. A value of -1. causes the geocentric right ascension of the excess velocity to be 180 degrees from that of the initial primer.

RADODD
Radius of primary target. Input only when MOPT3 = 11. Related to CNI, ECI, OMI, SAI, SOI, TPI, and EMUODD. [meters]

RADODX
Array of five elements pertaining to the radii of intermediate targets. These inputs are not used at present.

RAP
Apoapse distance of capture orbit about primary target. [planet radii]

REVS
Number of complete revolutions of the ballistic trajectory generated when the associated input MOPT is used. Must be a positive whole number.

RPER
Periapse distance of capture orbit about primary target. [planet radii]

SAI
Semi-major axis of primary-target orbit (must be positive). Input only when MOPT3 = 11. Related to CNI, ECI, OMI, SOI, TPI, EMUODD, and RADODD. [AU]

SAIX
Array of five elements, the first three of which may be currently used. Semi-major axes of intermediate-target orbits (must be positive). Input SAIX(i) only when MOPTX(i) = 11. Related to CNIX, ECIX, OMIX, SOIX, TPIX, EMUODX, and RADODX. [AU]

SOI
Argument of perihelion of primary-target orbit. Input only when MOPT3 = 11. Related to CNI, ECI, OMI, SAI, TPI, EMUODD, and RADODD. [deg]

SOIX
Array of five elements, the first three of which may be currently used. Arguments of perihelion of intermediate-target orbits. Input SOIX(i) only when MOPTX(i) = 11. Related to CNIX, ECIX, OMIX, SAIX, TPIX, EMUODX, and RADODX. [deg]

SPIRET   Retro-stage specific impulse (pertaining to the retro-maneuver at the primary target). [sec]

STATE   Array of six elements containing the Cartesian position and velocity components of the primary target. Use only when MOPT2 = 0 and the trigger settings of Y1(2) through Y6(2) are 0 or 1. [AU, AU/tau]
(tau = 58.132440991 days)

STEP1   Thrust-phase computation step size, $\Delta u$.

STEP2   Coast-phase computation step size, $\Delta \beta$.

TCOAST   Array of twenty elements, consisting of the durations of the coast phases corresponding to the coast-phase start-times input in the associated array TOFF. [days]

TDV   Time of occurrence of an impulsive deep space burn, in days from the start of the trajectory, which may be used only if the entire trajectory is ballistic (i.e., electric propulsion is not permitted with this option, nor is a third intermediate target). Iterator independent variables X64, X65, and X66 must be turned on, as these are used as the $\Delta v$ vector components of the deep space burn in EMOS. Also, set MAXHAM = 0. The following special feature is available regarding a first intermediate-target. If 1.D5 < TDV < 2.D5, then the burn occurs (TDV - 1.D5) days after passage of that target; if TDV > 2.D5, the burn occurs (TDV - 2.D5) days before passage of that target. [days]

TGO   Ballistic trajectory-extension print option. When zero, no action. When positive, TGO = the number of days that the trajectory is to extend ballistically beyond the primary-target when no swingby-continuation is requested, and ballistically beyond the (last) post-swingby target when swingby-continuation is requested (in addition to the post-swingby trajectory segment itself). Any negative value will invoke printout of only the post-swingby trajectory segment or segments when swingby-continuation is requested. Applies also to trajectories with multiple swingbys. [days]

| THRET | Retro-stage thrust, used only when MTMASS = 2. [lbs] |
|-------|-------|
| TOFF | Array of twenty elements, consisting of the times, in days from the start of the trajectory, at which imposed coast phases are to begin. Times must be in ascending order. Related to TCOAST. [days] |
| TPI | Time from reference date (MYEAR, etc.) to perihelion passage, for the primary target. Input only when MOPT3 = 11. Related to CNI, ECI, OMI, SAI, SOI, EMUODD, and RADODD. [days] |
| TPIX | Array of five elements, the first three of which may be currently used. Times from reference date (MYEAR, etc.) to perihelion passages, for the intermediate targets. Input TPIX(i) only when MOPTX(i) = 11. Related to CNIX, ECIX, OMIX, SAIX, SOIX, EMUODX, and RADODX. [days] |
| TPOWER | Solar-cell degradation characteristic-time; nuclear electric propulsion radioactive-decay characteristic-time. Related to MPOW. [days] |
| TSCALE | Iterator dependent-variable tolerance-interval scaling factor; scales all tolerances multiplicatively by the amount TSCALE. |
| T2 | Array of ten elements consisting of initial estimates of swingby-continuation trajectory-segment flight-times, i.e., T2(i) correspond to MOPT4(i). [days] |
| XANG1 | Latitude of the launch site. Used only if LAUNCH is non-zero. Related to XANG2. [deg] |
| XANG2 | Maximum parking orbit inclination, permitted by range safety considerations. Used only if LAUNCH is non-zero. Related to XANG1. [deg] |
| XSWING | Array of velocity vectors consisting of initial velocity guesses of a given post-swingby trajectory segment. Used only when either NSWING or MSWING has a value of -4 or -5. See especially the description of MSWING = -4. Velocity consists of exactly the same values as found in the V1, V2, V3 locations of the (Continued on next page). |

XSWING
(cont)
trajectory block print (first block). Related to MSWING, NSWING, MOPT4, and T2. [AU/tau]

X0
Array of seven elements, the first six of which contain the Cartesian position and velocity components of the launch planet. The seventh element is not used for input. Used only when MOPT2 = 0. [AU, AU/tau]

The following describes the iterator independent and dependent variable arrays of the boundary value problem. Input pertaining to the individual independent parameters is contained in the arrays X1 through X70. The independent-parameter arrays have five elements for each variable, as follows (where i = 1, 2, 3, ..., 70):

Xi(1)
Input value of parameter. Must be input regardless of trigger setting. If trigger is on (i.e., Xi(2) = 1), input value is used as initial guess of independent parameter and is varied at each subsequent iteration. If trigger is off, the parameter is not used as an independent parameter and is not changed.

Xi(2)
Trigger indicating whether parameter is to be an independent parameter in boundary value problem.

Xi(2) = 0   Not an independent parameter. (Trigger is "off").

1   Use as independent parameter. (Trigger is "on").

Xi(3)
Maximum change to parameter permitted in a single iteration. Should be a positive quantity. Used only if trigger is on. Units are same as that of the parameter.

Xi(4)
Perturbation increment used to compute partial derivatives by finite differences. Used only if trigger is on. Units are same as that of the parameter.

Xi(5)
Weighting factor. Should be a positive quantity. A value of 1. is generally recommended. The larger the weighting factor, the more the parameter is inhibited from varying. Used only if trigger is on.

50

The independent variables are as follows:

| | | |
|---|---|---|
| X1 | $\Lambda_o(1)$ | |
| X2 | $\Lambda_o(2)$ | Initial primer vector. |
| X3 | $\Lambda_o(3)$ | |
| X4 | $\dot{\Lambda}_o(1)$ | |
| X5 | $\dot{\Lambda}_o(2)$ | Initial primer derivative. |
| X6 | $\dot{\Lambda}_o(3)$ | |
| X7 | $\lambda_{\nu o}$ | Initial mass-ratio adjoint-variable. |
| X8 | $\lambda_\tau$ | Propulsion-time adjoint-variable. |
| X9 | | Not used. |
| X10 | $\delta$ | Geocentric declination of launch hyperbolic excess velocity. [deg] |

There is no conversion from input to internal units for any of the adjoint variables.

| | |
|---|---|
| X11 | Reference thrust acceleration, g. $[m/sec^2]$ |
| X12 | Electric propulsion system jet exhaust speed, c. [m/sec] |
| X13 | Launch hyperbolic excess speed, $v_{\infty o}$. [m/sec] |
| X14 | Hyperbolic excess speed at primary target, $v_{\infty n}$. [m/sec] |
| X15 | Initial time, $t_o$, measured from the reference date (MYEAR, etc.). [days] |
| X16 | Time at the primary target, $t_n$, measured from the reference date (MYEAR, etc.). [days] |

| | | |
|---|---|---|
| X17 | | Launch parking orbit inclination, i. Used only if LAUNCH $\neq$ 0. Optimized internally by the program if both X17 and Y17 triggers are off. [deg] |
| X18 | $\dot{x}_o$ | |
| X19 | $\dot{y}_o$ | Initial spacecraft heliocentric velocity. Not required unless one of the three triggers is on. [AU/tau] (tau = 58.132440991 days) |
| X20 | $\dot{z}_o$ | |
| X21 | | Constant thrust cone-angle, $\phi$. Non-zero value invokes the constant-$\phi$ constraint. $0 < \phi \leq 180^{\circ}$. Zero-value implies that $\phi$ is optimized along the trajectory (variable $\phi$). [deg] |

X22 through X29 are currently not used (although some locations following X21 are reserved for additional constant thrust cone-angles).

| | | |
|---|---|---|
| X30 | $\lambda_s$ | Degradation-time adjoint-variable. |

X31 through X40 are currently not used. X41 through X50 pertain to the first intermediate target, X51 through X60 pertain to the second intermediate target, and X61 through X70 pertain to the third intermediate target. The corresponding intermediate-target parameters are ignored if the intermediate target is absent. Subscripts 1, 2, and 3 pertain to the first, second, and third intermediate targets, respectively.

| | | |
|---|---|---|
| X41 | $\Lambda_1(1)$ | |
| X42 | $\Lambda_1(2)$ | Primer vector (at start of trajectory segment) |
| X43 | $\Lambda_1(3)$ | |
| X44 | $\dot{\Lambda}_1(1)$ | |
| X45 | $\dot{\Lambda}_1(2)$ | Primer derivative (at start of trajectory segment) |
| X46 | $\dot{\Lambda}_1(3)$ | |

| X47 | Encounter speed at first intermediate target, $v_{\infty 1}$. [m/sec] |

| X48 | Time at the first intermediate target, $t_1$, measured from the reference date (MYEAR, etc.). [days] |

| X49 | Sample-mass factor, $k_{samp\ 1}$, for sample-retrieval at first intermediate target. |

| X50 | Drop-mass factor, $k_{drop\ 1}$, for instrument-package dropoff at first intermediate target. |

The independent variables X51 through X60 and X61 through X70 are identical to X41 through X50 except that they pertain to the second and third intermediate targets, respectively. A third intermediate target may not be present when simulating ballistic missions having a deep space burn (See TDV), in which case X64, X65, and X66 are used as follows:

| X64 | $\Delta\dot{x}$ | |
| X65 | $\Delta\dot{y}$ | Deep-space velocity-increment. [AU/tau] |
| X66 | $\Delta\dot{z}$ | |

Inputs pertaining to the individual dependent parameters are contained in the arrays Y1 through Y70. The dependent-parameter arrays have three elements for each variable, as follows (where $i = 1, 2, 3, \ldots, 70$):

| Yi(1) | Desired value of the dependent parameter. |

| Yi(2) | Trigger. If off (i.e., equal to zero), the parameter is ignored and is not considered a dependent parameter. Then the other two inputs pertaining to the parameter need not be input. If trigger is on (i.e., not equal to zero), the parameter is considered to be a dependent parameter or constraint. Certain of the parameters may have |

| | Yi(2) (cont) | up to three non-zero trigger settings. These will be discussed individually below. |

Yi(2)
(cont)   up to three non-zero trigger settings. These will be discussed individually below.

Yi(3)   Tolerance of desired value (full interval width).

It should be noted that the transversality conditions, which comprise some of the parameters, are developed under the assumption that all constraints are of the point constraint type. Therefore, the satisfy-mode is sufficient in solving any optimization problems for which a complete set of transversality conditions is available.

The dependent-parameter arrays are as given below. $T(x)$ represents "the transversality condition associated with $x$" and the function $T(x)$ will have different values depending upon the constraints imposed on the problem. See NOMENCLATURE of reference [1] for definition of symbols and subscripts.

|  | Trigger 1 |  |  | Trigger 2 | Trigger 3 |  |
|---|---|---|---|---|---|---|
| Y1 | $\Delta x_n$ [AU] | ' | $a$ [AU] | Solar distance* [AU] | $T(\sigma)$ |  |
| Y2 | $\Delta y_n$ [AU] | ' | $e$ | $T(\theta_t)$* | $T(\theta_t)$ |  |
| Y3 | $\Delta z_n$ [AU] | ' | $i$ [deg] |  | $T(t_n)$ | NERVA |
| Y4 | $\Delta \dot{x}_n$ [AU/tau] | ' | $T(\Omega)$ | $T(\dot{x}_n)$ | $T(\xi)$ |  |
| Y5 | $\Delta \dot{y}_n$ [AU/tau] | ' | $T(\omega)$ | $T(\dot{y}_n)$ optimal flyby | $v_{\infty 0}$ |  |
| Y6 | $\Delta \dot{z}_n$ [AU/tau] | ' | $T(f)$ | $T(\dot{z}_n)$ | $T(\lambda)$ |  |

*Applicable only for two-dimensional motion in the $xy$ plane. Also requires that MOPT2 = 0.

Under Trigger 1 above, the first set of conditions applies to ordinary targeting conditions for position and velocity, and also to extra-ecliptic conditions to be satisfied when IOUT = 1; the second set of conditions applies to extra-ecliptic missions when IOUT = 2. $T(\Omega)$, $T(\omega)$, and $T(f)$ are symbols for the transversality

conditions yielding optimum final node angle, argument of perihelion, and true anomaly, respectively.

|  | Trigger 1 | Trigger 2 | Trigger 3 |
|---|---|---|---|
| Y7 | $\nu_n$ | $\lambda_{\nu n}$ | $m_{net}$ [kg] |
| Y8 | $T(\tau)$ | $\tau$ [days] | |
| Y9 | Currently not used. | | |
| Y10 | $T(\delta)$ | $\delta$ [deg] | Used only if LAUNCH $\neq 0$. |
| Y11 | $T(g)$ | $g$ [m/sec$^2$] | $p_{ref}$ [kw] |
| Y12 | $T(c)$ | $c$ [m/sec] | |
| Y13 | $T(v_{\infty o})$ | $v_{\infty o}$ [m/sec] | |
| Y14 | $T(v_{\infty n})$ | $v_{\infty n}$ [m/sec] | extra-ecliptic inclination [deg] |
| Y15 | $T(t_o)$ | $t_o$ [days] | |
| Y16 | $T(t_n)$ | $t_n$ [days] | $t_n - t_o$ [days]* |

*Time transversality with flight time fixed is assigned to Y15 under trigger 1.

| Y17 | $T(i)$ | $i$ [deg], where $i$ = parking orbit inclination. | Used only if LAUNCH $\neq 0$. |
|---|---|---|---|
| Y18 | $T(\dot{x}_o)$ | $\dot{x}_o$ [AU/tau] | |
| Y19 | $T(\dot{y}_o)$ | $\dot{y}_o$ [AU/tau] | |
| Y20 | $T(\dot{z}_o)$ | $\dot{z}_o$ [AU/tau] | |
| Y21 | $T(\phi)$ | $\phi$ [deg] for $\phi$ = constant with time. | |

Y22 through Y29 are currently not used.

| | Trigger 1 | Trigger 2 | |
|---|---|---|---|

$$Y30 \qquad T(s) \qquad s\ [days] \qquad \text{(Degradation time)}$$

Y31 through Y40 are currently not used. Y41 through Y50 pertain to the first intermediate target.

$$Y41 \qquad \Delta x_1\ [AU]$$

$$Y42 \qquad \Delta y_1\ [AU]$$

$$Y43 \qquad \Delta z_1\ [AU]$$

$$Y44 \qquad \Delta \dot{x}_1\ [AU/tau]\,,\ T(\dot{x}_1)$$

$$Y45 \qquad \Delta \dot{y}_1\ [AU/tau]\,,\ T(\dot{y}_1) \quad \left.\begin{array}{c}\end{array}\right\} \text{optimal flyby}$$

$$Y46 \qquad \Delta \dot{z}_1\ [AU/tau]\,,\ T(\dot{z}_1)$$

$$Y47 \qquad\qquad\qquad v_{\infty 1}\ [m/sec]$$

$$Y48 \qquad T(t_1) \qquad t_1\ [days]$$

$$Y49 \qquad m_{samp\,1}\ [kg]$$

$$Y50 \qquad m_{drop\,1}\ [kg]$$

Y51 through Y60 and Y61 through Y70 are identical to Y41 through Y50 except that they pertain to the second and third intermediate targets, respectively.

## C.  DEFAULT VALUES OF INPUT PARAMETERS

The following is a complete, alphabetical list of the default values of program input quantities having non-zero default values, except for the iterator arrays. All other inputs are zeroed. The default values of the iterator arrays $X_i(1)$, $X_i(2)$, $Y_i(1)$, and $Y_i(2)$, for $i = 1, 2, 3, \ldots, 70$, are zero, and the default values of $X_i(3)$ through $X_i(5)$ and $Y_i(3)$ for the same range of $i$ are listed in the listing of program inputs of Sample Case C.

| | | | |
|---|---|---|---|
| ALPHAA | 15. | NSET(3) | 300 |
| ALPHAT | 15. | NSET(5) | 300 |
| AN | 1.5 | NSWPAR | 1 |
| AR | 1. | NTAPE | 17 |
| BI | .76 | POWFIX | -1. |
| CTANK | .03 | PSIGN | 1. |
| CTRET | 1/9 | RADODD | 1. |
| DI | 13. | RAP | 38. |
| GAMMAX | 1. | RPER | 2. |
| GAP | .0001 | SAI | 1. |
| HOUR | 12. | SPIRET | 300. |
| IRK | 1 | STATE(1) | 1. |
| IRL | 1 | STATE(5) | 1. |
| ITF | 3 | STEP1 | .03125 |
| MAXHAM | 5 | STEP2 | .125 |
| MDAY | 1 | TDV | -1. |
| MODE | 4 | TGO | -1. |
| MONTH | 1 | THRET | 400. |
| MOPT3 | 10 | TOFF | 20*-1. |
| MUPDAT | 1 | TPOWER | 10.**30 |
| MYEAR | 1975 | TSCALE | 1. |
| NDIST | 3 | T2(i) | 50*i |
| NHUNG | 25 | X0(1) | 1. |
| NPRINT | 7 | X0(5) | 1.0000015 |

IV.    SAMPLE PROBLEMS AND RESULTS

Three sample cases have been selected for presentation in the following pages. Each case was selected to display the use of one or more new features that have been added to the program. The first case is an extra-ecliptic mission that exhibits the effects of high launch asymptote declinations on launch vehicle performance and the low thrust trajectory. This case also displays the housekeeping power option that was recently added to the program. The second case is a comet rendezvous mission which includes the effects of solar array degradation due to radiation effects. The third and final case displays the HILTOP's powerful capability for ballistic mission design and optimization. The specific mission chosen is a cometary flyby past Giacobini-Zinner followed by a deep space burn 10 days after passage, a return to and swingby of Earth (unpowered), a second swingby of Earth (powered), and finally encountering the comet Borrelly nearly 1023 days from launch. The tremendous flexibility for creating imaginative, multi-target mission profiles is demonstrated in this example.

## A. EXTRA ECLIPTIC MISSION

The objective of this mission is to place maximum payload in a circular orbit of 1.001 AU radius inclined 45 degrees to the ecliptic. The mission is $2\frac{1}{2}$ years (912.5 days) in duration and departs from Earth parking orbit on April 21, 1979. The solution given in this example is contained in the class of six-burn solutions which, for the mission duration assumed, tends to restrain the trajectory from deviating far from the nominal 1 AU solar distance. The specific case chosen uses the Titan III E/Centaur launch vehicle. The reference power (the power delivered to the power conditioners at 1 AU) is 20.35 kw and the specific impulse of the thrusters is 3000 seconds. The launch excess speed is optimized. The extra-ecliptic end conditions are invoked by setting IOUT = 1 and defining the desired values for AR, AE and AAI, the radius, eccentricity and inclination, respectively.

This case exhibits the use of several optional features of the program. A total of 0.65 kw of power developed by the solar arrays is reserved for housekeeping (non-propulsive) uses. This option is triggered with the input DPOW which is the ratio of housekeeping power to reference power. The power delivered to the power conditioners at distances below 1 AU is not permitted to exceed that delivered at 1 AU. This constraint is invoked by setting MODE equal to 5 and GAMMAX (the maximum permissible value of the power factor $\gamma$) equal to 1. The effects of launch asymptote declination are included in the launch vehicle performance model by setting LAUNCH equal to 1. The equatorial inclination of the launch parking orbit is limited to a maximum of 36 degrees through the input parameter XANG2. Since the geocentric declination of the launch asymptote for extra ecliptic missions is usually much greater than this inclination limit, the solution will include a non-coplanar injection maneuver from the launch parking orbit. The declination of the launch asymptote is optimized. Finally, the option of inputting the coefficients of the power profile is illustrated. The inputs for this case are listed on the next page.

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It should be noted that the choice of final orbit radius of 1.001 AU rather than 1.0 AU was made to alleviate numerical difficulties arising as a result of the corner in the power curve at 1 AU. Neighboring trajectories terminating on opposite sides of the corner point tend to possess different partial derivatives (i.e., they will behave differently when subjected to the same perturbation). Consequently, if the final desired distance is exactly the point of the discontinuity, one might expect convergence retardation when the end conditions are nearly satisfied.

```
&MINPUT X1(2)=1.D0,X2(2)=1.D0,X3(2)=1.D0,X4(2)=1.D0,X5(2)=1.D0
X6(2)=1.D0,X7=1.D0,X10(2)=1.D0,X11(2)=1.D0,X12=2.941995D4
X13(2)=1.D0,X15=3.1037DD1,X16=9.4353702
Y1(2)=1.D0,Y2(2)=1.D0,Y3(2)=1.D0,Y4(2)=1.D0,Y5(2)=1.D0,Y6(2)=1.D0
Y10(2)=1.D0,Y11=20.35D0,3.D0,Y13(2)=1.D0
LAUNCH=1,MBOOST=15,MTMASS=3,MODE=5
MOPT2=3,MOPT3=0,MYEAR=1979,MONTH=3,MDAY=21
BI=.63D0,DI=0.D0,CTANK=.035D0,GAMMAX=1.D0,DPOW=3.1941031941D3D-2
IOUT=1,AAI=45.D0,AR=1.001D0,XANG1=28.5D0,XANG2=36.D0
ASOL=1.4382D0,0.D0,-.2235D0,0.D0,-.2147D0
 X1=-1.849269016836D-02, X2=-3.444545869687D-01, X3=-5.292394680826D 00
 X4= 7.283860051662D-01, X5= 6.489958277263D-01, X6=-3.277641804973D-01
X10=-3.809150729556D 01,X11= 2.790574061256D-04,X13= 5.328606534645D 03
&END
```

| | | | | | |
|---|---|---|---|---|---|
| X59 = 0.0 | 0.0 | . | 3.000000000000000D 00 | 1.000000000000000D-08 | 1.000000000000000D 00 |
| X60 = 0.0 | 0.0 | . | 3.000000000000000D 00 | 1.000000000000000D-08 | 1.000000000000000D 00 |
| X61 = 0.0 | 0.0 | . | 3.000000000000000D 00 | 1.000000000000000D-08 | 1.000000000000000D 00 |
| X62 = 0.0 | 0.0 | . | 3.000000000000000D 00 | 1.000000000000000D-08 | 1.000000000000000D 00 |
| X63 = 0.0 | 0.0 | . | 3.000000000000000D 00 | 1.000000000000000D-08 | 1.000000000000000D 00 |
| X64 = 0.0 | 0.0 | . | 3.000000000000000D 00 | 1.000000000000000D-08 | 1.000000000000000D 00 |
| X65 = 0.0 | 0.0 | . | 3.000000000000000D 00 | 1.000000000000000D-08 | 1.000000000000000D 00 |
| X66 = 0.0 | 0.0 | . | 3.000000000000000D 00 | 1.000000000000000D-08 | 1.000000000000000D 00 |
| X67 = 0.0 | 0.0 | . | 3.000000000000000D 02 | 9.999999999990D-05 | 1.000000000000000D 00 |
| X68 = 0.0 | 0.0 | . | 5.000000000000000D 01 | 9.999999999990D-07 | 1.000000000000000D 00 |
| X69 = 0.0 | 0.0 | . | 5.000000000000000D 00 | 1.000000000000000D-08 | 1.000000000000000D 00 |
| X70 = 0.0 | 0.0 | . | 3.000000000000000D 00 | 1.000000000000000D-08 | 1.000000000000000D 00 |
| Y 1 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y 2 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y 3 = 0.0 | 0.0 | 1.000000000000000D 00 | 9.999999999999990D-05 | | |
| Y 4 = 0.0 | 0.0 | 1.000000000000000D 00 | 9.999999999999990D-05 | | |
| Y 5 = 0.0 | 0.0 | 1.000000000000000D 00 | 9.999999999999990D-05 | | |
| Y 6 = 0.0 | 0.0 | 1.000000000000000D 00 | 9.999999999999990D-05 | | |
| Y 7 = 0.0 | 0.0 | 1.000000000000000D 00 | 9.999999999999990D-05 | | |
| Y 8 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y 9 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y10 = 0.0 | 0.0 | 1.000000000000000D 00 | 9.999999999999990D-05 | | |
| Y11 = 0.0 | 2.035000000000000D 01 | 3.000000000000000D 00 | 9.999999999999990D-05 | | |
| Y12 = 0.0 | 0.0 | 1.000000000000000D 00 | 9.999999999999990D-05 | | |
| Y13 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y14 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y15 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y16 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y17 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y18 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y19 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y20 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y21 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y22 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y23 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y24 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y25 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y26 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y27 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y28 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y29 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y30 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y31 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y32 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y33 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y34 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y35 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y36 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y37 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y38 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y39 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y40 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y41 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y42 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y43 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y44 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y45 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y46 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y47 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y48 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y49 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y50 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y51 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y52 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y53 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |
| Y54 = 0.0 | 0.0 | . | 9.999999999999990D-05 | | |

```
Y55 =   0.0              ,    0.0              ,   9.999999999999999D-05,
Y56 =   0.0              ,    0.0              ,   9.999999999999999D-05,
Y57 =   0.0              ,    0.0              ,   9.999999999999999D-05,
Y58 =   0.0              ,    0.0              ,   9.999999999999999D-05,
Y59 =   0.0              ,    0.0              ,   9.999999999999999D-05,
Y60 =   0.0              ,    0.0              ,   9.999999999999999D-05,
Y61 =   0.0              ,    0.0              ,   9.999999999999999D-05,
Y62 =   0.0              ,    0.0              ,   9.999999999999999D-05,
Y63 =   0.0              ,    0.0              ,   9.999999999999999D-05,
Y64 =   0.0              ,    0.0              ,   9.999999999999999D-05,
Y65 =   0.0              ,    0.0              ,   9.999999999999999D-05,
Y66 =   0.0              ,    0.0              ,   9.999999999999999D-05,
Y67 =   0.0              ,    0.0              ,   9.999999999999999D-05,
Y68 =   0.0              ,    0.0              ,   9.999999999999999D-05,
Y69 =   0.0              ,    0.0              ,   9.999999999999999D-05,
Y70 =   0.0              ,    0.0              ,   9.999999999999999D-05,
&OUTPUT
AAI=  45.00000000000000     ,AE= 0.0                  ,ALPHAA=  15.00000000000000      ,ALPHAT=  15.00000000000000      ,ALTITU=
0.0                  ,AN=  1.500000000000000      ,AR=  1.001000000000000      ,ASOL=  1.438200000000000      ,  0.0
-0.2235000000000000    ,  0.0                   ,-0.2147000000000000       ,BI= 0.6300000000000000      ,BI= 0.0                 ,B2=
0.0                  ,B3= 0.0                  ,CNI= 0.0                 ,CNIX= 0.0                  ,  0.0
0.0                  ,  0.0                   ,  0.0                    ,CSTR= 0.0                 ,CTANK= 0.3499999999999999D-01,
CTRET= 0.1111111111111111     ,DI= 0.0                  ,DMRETR= 0.0                ,DPOW= 0.3194103194103999D-01,ECI=
0.0                  ,ECIX= 0.0                 ,  0.0                    ,  0.0                    ,  0.0
0.0                  ,EI= 0.0                  ,EMUODD= 0.0               ,EMJODX= 0.0               ,GAMMAX=  1.000000000000000      ,GAP=
0.9999999999999999D-04,HOUR=  12.00000000000000      ,OMI= 0.0                 ,OMIX= 0.0                 ,POWFIX= -1.000000000000000      ,
0.0                  ,  0.0                   ,  0.0                    ,  0.0                    ,  0.0
PSIGN=  1.000000000000000      ,RADODD=  1.000000000000000      ,RADODX= 0.0                ,RAP=  38.00000000000000      ,REVS= 0.0
0.0                  ,  0.0                   ,  0.0                    ,  0.0                    ,  0.0
RPER=  2.000000000000000      ,SAI=  1.000000000000000      ,SAIX= 0.0                 ,SOI= 0.0                 ,SOIX= 0.0
0.0                  ,  0.0                   ,  0.0                    ,  0.0                    ,SPIRET=  300.0000000000000
0.0                  ,  0.0                   ,  0.0                    ,  0.0                    ,  1.000000000000000
STATE=  1.000000000000000      ,  0.0          ,  0.0                    ,  0.0                    ,
0.0                  ,STEP1= 0.3125000000000000D-01,STEP2= 0.1250000000000000      ,TCOAST= 0.0
0.0                  ,  0.0                   ,  0.0                    ,  0.0
0.0                  ,  0.0                   ,  0.0                    ,  0.0
0.0                  ,  0.0                   ,  0.0                    ,  0.0
0.0                  ,  0.0                   ,  0.0                    ,TDV= -1.000000000000000      ,TGO=
-1.000000000000000      ,THRET=  400.0000000000000      ,TOFF= -1.000000000000000      , -1.000000000000000      , -1.000000000000000
-1.000000000000000      , -1.000000000000000      , -1.000000000000000      , -1.000000000000000      , -1.000000000000000
-1.000000000000000      , -1.000000000000000      , -1.000000000000000      , -1.000000000000000      , -1.000000000000000
-1.000000000000000      , -1.000000000000000      , -1.000000000000000      , -1.000000000000000      ,  0.0
-1.000000000000000      , -1.000000000000000      ,TPI= 0.0                 ,TPIX= 0.0                 ,  0.0
0.0                  ,  0.0                   ,  0.0                    ,TPOWER= 0.1000000000000000D 31,TSCALE=
1.000000000000000      ,T2=  50.00000000000000      ,  100.0000000000000      ,  150.0000000000000      ,  200.0000000000000
250.0000000000000      ,  300.0000000000000      ,  350.0000000000000      ,  400.0000000000000      ,  450.0000000000000
500.0000000000000      ,XANG1=  28.50000000000000      ,XANG2=  36.00000000000000      ,XSWING= 0.0
0.0                  ,  0.0                   ,  0.0                    ,  0.0                    ,  0.0
0.0                  ,  0.0                   ,  0.0                    ,  0.0                    ,  0.0
0.0                  ,  0.0                   ,  0.0                    ,  0.0                    ,  0.0
0.0                  ,  0.0                   ,  0.0                    ,  0.0                    ,  0.0
0.0                  ,  0.0                   ,  0.0                    ,  0.0                    ,XO=  1.000000000000000
0.0                  ,  0.0                   ,  0.0                    ,  0.0                    ,  0.0
0.0                  ,IBAL=            0,INTPR=           0,IOJT=            1,IRK=            1,IRL=            1,IROT=            0,ISPIN=
0,ITF=            3,ITPRNT=           0,JPP=            0,JPRINT=           0,JT=            0,KPART=            5,LAUNCH=           3,MOPT=
1,LOADX=           0,MAXHAM=           5,MBOOST=          15,MDAY=          21,MODE=            5,MONTH=            3,MOPT=
0,MOPTX=           0,           0,           0,           0,           0,MOPT2=            3,MOPT3=           0,MOPT4=           0,
MPRINT=          0,MPUNCH=           0,MREAD=           0,MSWING=          0,           0,           0,           0,           0,
0,           0,           0,           0,MTMASS=           3,MUPDAT=           1,MYEAR=         1979,NDIST=
3,NHUNG=          25,NORMAL=           0,NPERF=           0,NPRINT=            7,NSET=           0,           0,         300,
0,          300,NSWING=           0,NSWPAR=           1,NTAPE=           17
&END
```

```
----------------------------------------------------------------------------------------------------------------------
---------- NOMINAL TRAJECTORY  1 (TOTAL   1) ---------- INHIBITOR IS   5.8208D-11 ------------------------------------
----------------------------------------------------------------------------------------------------------------------
                                         INDEPENDENT PARAMETERS
  1.PRIM1(-1.8492690D-02)    2.PRIM2(-3.4445459D-01)    3.PRIM3(-5.2929947D 00)    4.PDOT1( 7.2838601D-01)    5.PDOT2( 6.4899583D-01)
  6.PDOT3(-3.2776418D-01)   10.DECLN(-3.8091507D 01)   11.ACCEL( 2.7905741D-04)   13.VINF1( 5.3286065D 03)
                                         DEPENDENT PARAMETERS
  1.DELTA X( 1.36734D-02)    2.DELTA Y(-2.04257D-02)    3.DELTA Z( 2.52203D-02)    4.DELT XD( 1.62397D-02)    5.DELT YD(-2.40807D-02)
  6.DELT ZD( 2.57904D-02)   10.T.DECLN( 1.75024D-09)   11. POWER ( 2.03500D 01)   13.T.VINF1(-3.71296D-09)
THRUST SWITCHING TIMES (DAYS)        0.0     ON       80.374  OFF      103.276  ON      218.909  OFF     247.259  ON       399.777  OFF
     439.175  ON      567.999  OFF      618.895  ON      749.493  OFF      809.322  ON      912.533  ON
                                         ELECTRIC PROPULSION PARAMETERS
     POWER              EFFICIENCY          PROP TIME           J            PROP TIME RATIO        AVE ACCEL
     20.3499999990      0.6300000000        712.1252770929      11.3661826370     0.7804112626         0.0004309116
                                         MASS COMPONENT BREAKDOWN
     INITIAL            PROPULSION          PROPELLANT          TANKAGE         STRUCTURE            PAYLOAD
     3123.1976935923    620.2499999709      1813.3820629241     63.4683722023   0.0                  626.0972584950


----------------------------------------------------------------------------------------------------------------------
---------- NOMINAL TRAJECTORY  2 (TOTAL   4) ---------- INHIBITOR IS   1.8190D-12 ------------------------------------
----------------------------------------------------------------------------------------------------------------------
                                         INDEPENDENT PARAMETERS
  1.PRIM1(-9.0058542D-03)    2.PRIM2(-3.5175913D-01)    3.PRIM3(-5.2008632D 00)    4.PDOT1( 6.9910970D-01)    5.PDOT2( 6.2888718D-01)
  6.PDOT3(-3.3398207D-01)   10.DECLN(-3.7843959D 01)   11.ACCEL( 2.6655743D-04)   13.VINF1( 5.1101377D 03)
                                         DEPENDENT PARAMETERS
  1.DELTA X(-1.06725D-05)    2.DELTA Y(-9.99850D-04)    3.DELTA Z(-2.51111D-03)    4.DELT XD( 1.14983D-03)    5.DELT YD(-7.22438D-04)
  6.DELT ZD( 2.13528D-03)   10.T.DECLN( 2.70967D-03)   11. POWER ( 2.03067D 01)   13.T.VINF1(-1.69061D-03)
THRUST SWITCHING TIMES (DAYS)        0.0     ON       80.395  OFF      103.651  ON      219.584  OFF     247.918  ON       400.527  OFF
     439.396  ON      566.714  OFF      616.029  ON      747.829  OFF      804.878  ON      912.500  ON
                                         ELECTRIC PROPULSION PARAMETERS
     POWER              EFFICIENCY          PROP TIME           J            PROP TIME RATIO        AVE ACCEL
     20.3066573251      0.6300000000        715.6762058953      9.9909155678      0.7843026914         0.0004008460
                                         MASS COMPONENT BREAKDOWN
     INITIAL            PROPULSION          PROPELLANT          TANKAGE         STRUCTURE            PAYLOAD
     3262.5709661616    618.9289536062      1819.7281211922     63.5904842417   0.0                  760.2234071214


----------------------------------------------------------------------------------------------------------------------
---------- NOMINAL TRAJECTORY  3 (TOTAL   7) ---------- INHIBITOR IS   5.6843D-14 ------------------------------------
----------------------------------------------------------------------------------------------------------------------
                                         INDEPENDENT PARAMETERS
  1.PRIM1( 2.2736015D-03)    2.PRIM2(-3.7436282D-01)    3.PRIM3(-5.1922367D 00)    4.PDOT1( 7.0903573D-01)    5.PDOT2( 6.3603250D-01)
  6.PDOT3(-3.2226660D-01)   10.DECLN(-3.7854840D 01)   11.ACCEL( 2.6660044D-04)   13.VINF1( 5.0985903D 03)
                                         DEPENDENT PARAMETERS
  1.DELTA X( 9.71723D-04)    2.DELTA Y(-4.33226D-04)    3.DELTA Z(-1.01801D-03)    4.DELT XD(-5.13886D-04)    5.DELT YD( 4.32699D-05)
  6.DELT ZD( 3.84511D-04)   10.T.DECLN(-3.74522D-05)   11. POWER ( 2.03500D 01)   13.T.VINF1( 3.24076D-05)
THRUST SWITCHING TIMES (DAYS)        0.0     ON       80.299  OFF      103.546  ON      220.043  OFF     248.369  ON       400.927  OFF
     439.925  ON      568.200  OFF      617.759  ON      749.422  OFF      806.781  ON      912.500  ON
                                         ELECTRIC PROPULSION PARAMETERS
     POWER              EFFICIENCY          PROP TIME           J            PROP TIME RATIO        AVE ACCEL
     20.3499746867      0.6300000000        715.0113506695      9.8704819992      0.7835740829         0.0004006508
                                         MASS COMPONENT BREAKDOWN
     INITIAL            PROPULSION          PROPELLANT          TANKAGE         STRUCTURE            PAYLOAD
     3269.1258074603    620.2492284722      1821.6164813205     63.7565768462   0.0                  763.5035208214

THIS CASE IS CONVERGED.

     8 TRAJECTORIES WITHOUT PARTIAL DERIVATIVES AND   3 TRAJECTORIES WITH PARTIAL DERIVATIVES REQUIRED FOR THIS CASE.
```

| TIME | SEMI-MAJOR AXIS | ECCENTRICITY | INCLINATION | NODE | ARG POS | RMAG | TRAVEL |
|---|---|---|---|---|---|---|---|
| R1 | R2 | R3 | V1 | V2 | V3 | MASS RATIO | THRUST ACC |
| L1 | L2 | L3 | L4 | L5 | L6 | L7 | HAM |
| LG | LC | LPHI | CONE | CLOCK | HMAG | POWER FNCT | SWITCH FNCT |
| PSI | THETA | PHI | LATITUDE | LONGITUDE | FLT PTH ANG_E | VMAG | PROP TIME |

**EARTH**                      START OF TRAJECTORY. THRUST ON

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.0 | 8.98977775D-01 | 1.21180874D-01 | 9.22842759D 00 | 3.08348545D 01 | 1.80000000D 02 | 1.00498235D 00 | 0.0 |
| -8.62926339D-01 | -5.15119079D-01 | 0.0 | 4.96430685D-01 | -7.80199267D-01 | -1.50185351D-01 | 1.00000000D 00 | 4.46544954D-02 |
| 1.43302209D-03 | -3.71273470D-01 | -5.19222332D 00 | 7.08559146D-01 | 6.35286348D-01 | -3.26439161D-01 | 1.00000000D 00 | 9.49111444D-02 |
| 0.0 | 0.0 | 0.0 | 8.60527166D 01 | 1.71366591D 01 | 9.41156981D-01 | 9.93095163D-01 | 4.19307526D 00 |
| -7.70840302D 01 | 8.06481424D 01 | 8.79184672D 01 | 0.0 | -1.49165146D 02 | -1.61208637D 00 | 9.36851858D-01 | 0.0 |

SWITCH THRUST OFF

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8.03383162D 01 | 9.24015325D-01 | 1.03022217D-01 | 1.19678031D 01 | 4.06593345D 01 | 2.52732848D 02 | 8.89443736D-01 | 8.23696730D 01 |
| 3.41100615D-01 | -8.02334532D-01 | -1.76124469D-01 | 9.42332071D-01 | 5.25634816D-01 | -4.56244954D-02 | 9.37112533D-01 | 4.79824670D-02 |
| 3.97728374D-01 | -4.69486344D-02 | -1.11930619D 00 | -4.70177337D-02 | -6.32061682D-01 | 5.36711351D 00 | 1.25303011D 00 | 9.49111521D-02 |
| -3.87479887D 00 | -7.30163733D-02 | 0.0 | 8.74079507D 01 | 1.51105162D 01 | 9.56142362D-01 | 1.00000000D 00 | -3.99680289D-15 |
| -6.04197599D 01 | 4.47840023D 01 | 6.94899910D 01 | -1.14209389D 01 | -6.69679493D 01 | -5.51206966D 00 | 1.07998300D 00 | 8.03383162D 01 |

SWITCH THRUST ON

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1.03587476D 02 | 9.24015325D-01 | 1.03022217D-01 | 1.19678031D 01 | 4.05593345D 01 | 2.91687783D 02 | 8.52502666D-01 | 1.11324607D 02 |
| 6.63125730D-01 | -5.07008397D-01 | -1.73111372D-01 | 6.28717706D-01 | 9.29830855D-01 | 6.25834478D-02 | 9.37112533D-01 | 4.79824670D-02 |
| 4.07327513D-01 | -3.99412178D-01 | 1.04297296D 00 | 1.31127036D-01 | -1.05012549D 00 | 5.22760591D 00 | 1.25303011D 00 | 9.49111521D-02 |
| -3.87479887D 00 | -7.30163733D-02 | 0.0 | 9.04770078D 01 | 1.74834324D 02 | 9.56142362D-01 | 1.00000000D 00 | -1.33226763D-15 |
| 7.32179111D 01 | -3.52154795D 00 | 7.32505352D 01 | -1.17161055D 01 | -3.74005722D 01 | -3.91080390D 00 | 1.12418886D 00 | 8.03383162D 01 |

SWITCH THRUST OFF

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2.20047131D 02 | 9.26812233D-01 | 9.30891521D-02 | 1.57548141D 01 | 4.10752060D 01 | 7.03114536D 01 | 9.29508201D-01 | 2.60280593D 02 |
| -3.17352054D-01 | 8.40718021D-01 | 2.37626552D-01 | -9.84539937D-01 | -2.99723195D-01 | 1.18969743D-01 | 8.45914448D-01 | 5.31554595D-02 |
| -2.43332572D-01 | -6.42014437D-01 | 1.19757838D 00 | -8.53083278D-01 | 4.97309569D-01 | -4.74623336D 00 | 1.61188302D 00 | 9.49111675D-02 |
| -8.08440714D 00 | -2.04809354D-01 | 0.0 | 8.92745773D 01 | 1.62097586D 02 | 9.58530572D-01 | 1.00000000D 00 | -1.75415238D-14 |
| 6.39873057D 01 | 1.08435053D 02 | 9.79719829D 01 | 1.48119626D 01 | 1.10680388D 02 | 5.33875555D 00 | 1.03571631D 00 | 1.96797972D 02 |

SWITCH THRUST ON

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2.48414939D 02 | 9.26812233D-01 | 9.30891521D-02 | 1.57548141D 01 | 4.10752060D 01 | 9.98993508D 01 | 9.72918798D-01 | 2.89868490D 02 |
| -7.32170229D-01 | 5.85470285D-01 | 2.60235064D-01 | -6.83124837D-01 | -7.13729664D-01 | -2.51642405D-02 | 8.45914448D-01 | 5.31545595D-02 |
| -5.74162417D-01 | -3.78433842D-01 | -1.19695974D 00 | -4.74087039D-01 | 5.85741621D-01 | -4.83344864D 00 | 1.61188302D 00 | 9.49111675D-02 |
| -8.08440714D 00 | -2.04809354D-01 | 0.0 | 8.59477730D 01 | 3.68564479D 01 | 9.58530572D-01 | 1.00000000D 00 | 2.88657986D-15 |
| -5.84964179D 01 | 9.92381776D 01 | 9.48121931D 01 | 1.55142903D 01 | 1.41352882D 02 | 4.51038882D 00 | 9.88282761D-01 | 1.96797972D 02 |

| TIME | SEMI-MAJOR AXIS | ECCENTRICITY | INCLINATION | NODE | ARG POS | RMAG | TRAVEL |
|---|---|---|---|---|---|---|---|
| R1 | R2 | R3 | V1 | V2 | V3 | MASS RATIO | THRUST ACC |
| L1 | L2 | L3 | L4 | L5 | L6 | L7 | HAM |
| LG | LC | LPHI | CONE | CLOCK | HMAG | POWER FNCT | SWITCH FNCT |
| PSI | THETA | PHI | LATITUDE | LONGITUDE | FLT PTH ANGLE | VMAG | PROP TIME |

SWITCH THRUST OFF

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 4.010070630 02 | 9.928792430-01 | 4.021556660-02 | 2.212696930 01 | 3.931884210 01 | 2.479857700 02 | 9.758854130-01 | 4.361040980 02 |
| 2.480741360-01 | -8.801594050-01 | -3.407799650-01 | 9.467544780-01 | 3.587871210-01 | -1.313605680-01 | 7.276817250-01 | 6.179208530-02 |
| 2.355275990-01 | 2.135501880-01 | -1.692560920 00 | 4.523715280-01 | -1.130723800 00 | 4.568498310 00 | 2.337641390 00 | 9.491117440-02 |
| -1.559122360 01 | -4.386962160-01 | 0.0 | 9.627615370 31 | 9.566487680 00 | 9.956271730-01 | 1.000000000 00 | -2.220446050-16 |
| -6.605315360 01 | 4.903001100 01 | 7.456609170 01 | -2.043844010 01 | -7.425943680 01 | -2.085843000 00 | 1.020906030 00 | 3.493900950 02 |

SWITCH THRUST ON

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 4.399952240 02 | 9.928792430-01 | 4.021556660-02 | 2.212696930 01 | 3.931884210 01 | 2.890614300 02 | 9.566481040-01 | 4.771787580 02 |
| 7.724348930-01 | -4.500324890-01 | -3.405740610-01 | 5.472870230-01 | 8.751594840-01 | 1.342902270-01 | 7.276817250-01 | 6.179208530-02 |
| 6.064626030-01 | -7.884010370-01 | 1.405868520 00 | 6.783913500-01 | -1.640980790 00 | 4.292900070 00 | 2.337641390 00 | 9.491117440-02 |
| -1.559122360 01 | -4.386962160-01 | 0.0 | 1.006179130 02 | 1.827083360 02 | 9.956271730-01 | 1.000000000 00 | -1.421085470-14 |
| 7.682147830 01 | -2.349917260 01 | 7.793166960 01 | -2.085521470 01 | -3.022573790 01 | -9.691429060-01 | 1.040894360 00 | 3.493900950 02 |

SWITCH THRUST OFF

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5.681922520 02 | 9.880509530-01 | 2.609246950-02 | 2.853850540 01 | 3.927535380 01 | 6.348007860 01 | 9.915455740-01 | 6.113861470 02 |
| -1.506807640-01 | 8.836263620-01 | 4.238659990-01 | -9.469304810-01 | -2.402550930-01 | 2.248546780-01 | 6.272922520-01 | 7.168105630-02 |
| 2.747517860-01 | -8.126470770-01 | 1.796782390 00 | -1.208023700 00 | 1.539216380 00 | -3.874779500 00 | 3.135158230 00 | 9.491117390-02 |
| -2.149807820 01 | -7.147457240-01 | 0.0 | 7.881195510 01 | 1.826645970 02 | 9.936690950-01 | 1.000000000 00 | -1.998401440-15 |
| 8.021703660 01 | 8.963810900 01 | 8.993850920 01 | 2.530774630 01 | 9.967730200 01 | 1.481364300 00 | 1.002476670 00 | 4.775871220 02 |

SWITCH THRUST ON

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 6.177877340 02 | 9.880509530-01 | 2.609246950-02 | 2.853850640 01 | 3.927535380 01 | 1.119135000 02 | 1.009647160 00 | 6.598215690 02 |
| -8.126352050-01 | 3.984400910-01 | 4.475007360-01 | -5.138137410-01 | -8.222761690-01 | -1.692743930-01 | 6.272922520-01 | 7.072549660-02 |
| -7.595514920-01 | 6.687596400-01 | -1.714643090 00 | -1.113357320 00 | 1.737417860 00 | -3.831050020 00 | 3.135158230 00 | 9.491117390-02 |
| -2.149807820 01 | -7.147457240-01 | 0.0 | 7.332521910 01 | 3.489896040 00 | 9.936690950-01 | 9.866698260-01 | 0.0 |
| -8.496792010 01 | 4.865684340 01 | 8.667838360 01 | 2.630982250 01 | 1.538810000 02 | 8.167061320-01 | 9.842745950-01 | 4.775871220 02 |

SWITCH THRUST OFF

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7.496209950 02 | 1.008048750 00 | 1.322286570-02 | 3.669791410 01 | 3.858489670 01 | 2.399107740 02 | 9.988970520-01 | 7.869761060 02 |
| 4.073346740-02 | -8.540298070-01 | -5.164970410-01 | 9.313290970-01 | 2.348064760-01 | -2.961152850-01 | 5.254455040-01 | 8.557494710-02 |
| -6.461999620-01 | 8.699006430-01 | -2.032552950 00 | 1.220095780 00 | -1.967002170 00 | 3.548784520 00 | 4.329961250 00 | 9.491117310-02 |
| -2.835893440 01 | -1.095770480 00 | 0.0 | 1.072342150 02 | 3.476754720 02 | 1.003928530 00 | 1.000000000 00 | -1.332267630-15 |
| -8.130258780 01 | 3.625483640 01 | 8.299592590 01 | -3.113573920 01 | -8.726931260 01 | -5.508538470-01 | 1.005083490 00 | 6.094203840 02 |

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| TIME | SEMI-MAJOR AXIS | ECCENTRICITY | INCLINATION | NODE | ARG POS | RMAG | TRAVEL |
|---|---|---|---|---|---|---|---|
| R1 | R2 | R3 | V1 | V2 | V3 | MASS RATIO | THRUST ACC |
| L1 | L2 | L3 | L4 | L5 | L6 | L7 | HAM |
| LG | LC | LPHI | CONE | CLOCK | HMAG | POWER FNCT | SWITCH FNCT |
| PSI | THETA | PHI | LATITUDE | LONGITUDE | FLT PTH ANG_E | VMAG | PROP TIME |

SWITCH THRUST ON

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8.069674900 02 | 1.008048750 00 | 1.32228657D-02 | 3.669791413 01 | 3.858489670 01 | 2.97121540D 02 | 9.949174200-01 | 8.441868720 02 |
| 7.973548400-01 | -2.721259110-01 | -5.29181842D-01 | 4.738377590-01 | 8.478079300-01 | 2.736805820-01 | 5.254455040-01 | 8.557494710-02 |
| 7.835617570-01 | -1.42943432D 00 | 1.627366430 00 | 1.502294470 00 | -2.19533704D 00 | 3.286792330 00 | 4.329961250 00 | 9.491117310-02 |
| -2.835893440 01 | -1.09577048D 00 | 0.0 | 1.135914J7D 02 | 1.956872790 02 | 1.003928530 00 | 1.000000000 00 | -2.22044605D-16 |
| 7.946959820 01 | -6.863345320 01 | 8.618216410 01 | -3.213291830 01 | -1.39440461D 01 | 1.30096642D-01 | 1.009059750 00 | 6.09420384D 02 |

INPUT TARGET                                                                        END OF TRAJECTORY, THRUST ON

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 9.125000000 02 | 1.00106538D 00 | 9.482929380-05 | 4.499978363 01 | 3.676237590 01 | 4.27871776D 01 | 1.000974630 00 | 9.482619080 02 |
| 3.007513090-01 | 8.248284640-01 | 4.807877500-01 | -8.543975793-01 | 9.158705555-03 | 5.19688355D-01 | 4.428474530-01 | 1.01398543D-01 |
| 1.21941148D 00 | -1.874468100 00 | 2.728663000 00 | -1.264304910 J0 | 1.820503340 00 | -2.36961053D 00 | 5.782196730 00 | 9.491117590-02 |
| -3.47077081D 01 | -1.512366970 00 | 0.0 | 7.320874723 01 | 2.321395460 02 | 1.00053254D 00 | 9.986459540-01 | 9.491117590-02 |
| 8.381241470 01 | 6.962279920 01 | 8.784916900 01 | 2.870627380 J1 | 6.996698860 01 | -1.594932950-03 | 9.995583450-01 | 7.149528940 02 |

ITERATOR SUMMARY

INDEPENDENT PARAMETERS

```
 1,PRIMI( 1.4330221D-03)    2,PRIM2(-3.7127347D-01)    3,PRIM3(-5.1922233D 00)    4,PDOT1( 7.0855915D-01)    5,PDOT2( 6.3528635D-01)
 6,PDOT3(-3.2643916D-01)    7,LMASS( 1.0000000D 00)    8, LTAJ( 0.0          )    9,      ( 0.0          )   10,DECLN(-3.7853674D 01)
11,ACCEL( 2.6664805D-04)   12,V JET( 2.9419950D 04)   13,VINFI( 5.0995285D 03)   14,VINF2( 0.0          )   15,TIME1( 3.1037000D 01)
16,TIME2( 9.4353700D 02)   17,IPARK( 0.0          )   18,VE..31( 0.0          )   19,VELJ2( 0.0          )   20,VELO3( 0.0          )
21,THET1( 0.0          )   22,THET2( 0.0          )   23,THET3( 0.0          )   24,THET4( 0.0          )   25,THET5( 0.0          )
26,THET6( 0.0          )   27,THET7( 0.0          )   28,THET8( 0.0          )   29,THET9( 0.0          )   30,LDEGR( 0.0          )
31, PHI1( 0.0          )   32, PHI2( 0.0          )   33, PHI3( 0.0          )   34, PHI4( 0.0          )   35, PHI5( 0.0          )
36, PHI6( 0.0          )   37, PHI7( 0.0          )   38, PHI8( 0.0          )   39, PHI9( 0.0          )   40,PHI10( 0.0          )
41,PR1-A( 0.0          )   42,PR2-A( 0.0          )   43,PR3-A( 0.0          )   44,PD1-A( 0.0          )   45,PD2-A( 0.0          )
46,PD3-A( 0.0          )   47,VINFA( 0.0          )   48,TIMEA( 0.0          )   49,KSAMP( 0.0          )   50,KDROP( 0.0          )
51,PR1-B( 0.0          )   52,PR2-B( 0.0          )   53,PR3-B( 0.0          )   54,PD1-B( 0.0          )   55,PD2-B( 0.0          )
56,PD3-B( 0.0          )   57,VINFB( 0.0          )   58,TIME3( 0.0          )   59,KSAMP( 0.0          )   60,KDROP( 0.0          )
61,PR1-C( 0.0          )   62,PR2-C( 0.0          )   63,PR3-C( 0.0          )   64,PD1-C( 0.0          )   65,PD2-C( 0.0          )
66,PD3-C( 0.0          )   67,VINFC( 0.0          )   68,TIMEC( 0.0          )   69,KSAMP( 0.0          )   70,KDROP( 0.0          )
```

DEPENDENT PARAMETERS

```
 1,DELTA X( 3.625590D-05)    2,DELTA Y(-1.858040D-05)    3,DELTA Z(-4.362440D-05)    4,DELT XD(-4.200180D-05)    5,DELT YD( 2.217760D-05)
 6,DELT ZD( 4.213620D-05)    7,      ( 0.0          )    8,      ( 0.0          )    9,      ( 0.0          )   10,T.DECLN( 5.775980D-07)
11, POWER ( 2.035000D 01)   12,      ( 0.0          )   13,T.VINF1(-1.613580D-06)   14,      ( 0.0          )   15,      ( 0.0          )
16,      ( 0.0          )   17,      ( 0.0          )   18,      ( 0.0          )   19,      ( 0.0          )   20,      ( 0.0          )
21,      ( 0.0          )   22,      ( 0.0          )   23,      ( 0.0          )   24,      ( 0.0          )   25,      ( 0.0          )
26,      ( 0.0          )   27,      ( 0.0          )   28,      ( 0.0          )   29,      ( 0.0          )   30,      ( 0.0          )
31,      ( 0.0          )   32,      ( 0.0          )   33,      ( 0.0          )   34,      ( 0.0          )   35,      ( 0.0          )
36,      ( 0.0          )   37,      ( 0.0          )   38,      ( 0.0          )   39,      ( 0.0          )   40,      ( 0.0          )
41,      ( 0.0          )   42,      ( 0.0          )   43,      ( 0.0          )   44,      ( 0.0          )   45,      ( 0.0          )
46,      ( 0.0          )   47,      ( 0.0          )   48,      ( 0.0          )   49,      ( 0.0          )   50,      ( 0.0          )
51,      ( 0.0          )   52,      ( 0.0          )   53,      ( 0.0          )   54,      ( 0.0          )   55,      ( 0.0          )
56,      ( 0.0          )   57,      ( 0.0          )   58,      ( 0.0          )   59,      ( 0.0          )   60,      ( 0.0          )
61,      ( 0.0          )   62,      ( 0.0          )   63,      ( 0.0          )   64,      ( 0.0          )   65,      ( 0.0          )
66,      ( 0.0          )   67,      ( 0.0          )   68,      ( 0.0          )   69,      ( 0.0          )   70,      ( 0.0          )
```

```
THRUST SWITCHING TIMES (DAYS)        0.0    ON       80.338  OFF    103.587  ON     220.047  OFF     248.415  ON     401.007  OFF
    439.995  ON       568.192  OFF     617.788  ON      749.621  OFF    806.967  ON     912.500  ON
```

ELECTRIC PROPULSION PARAMETERS

| POWER | EFFICIENCY | PROP TIME | J | PROP TIME RATIO | AVE ACCEL |
|---|---|---|---|---|---|
| 20.3499990796 | 0.6300000000 | 714.9528938345 | 9.8696171166 | 0.7835100206 | 0.0004006926 |

MASS COMPONENT BREAKDOWN

| INITIAL | PROPULSION | PROPELLANT | TANKAGE | STRUCTURE | PAYLOAD |
|---|---|---|---|---|---|
| 3268.5460092059 | 620.2499719473 | 1821.0787330785 | 63.7377556577 | 0.0 | 763.4795485224 |

SWITCH-COUNT HISTORY    ALL 12

   422 THRUST COMPUTE STEPS.    32 COAST COMPUTE STEPS

LAUNCH ASYMPTOTE OFFSET FROM PRIMER =  -32.786 DEGREES.

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| I | TIME | ECLIPTIC LONGITUDE | | SOLAR DISTANCE | COMMUNICATION | ANGLE | | DISTANCE | | SWITCH FUNCTION | | PSI | | THRUST ANGLES THETA | | PHI | | INPUT POWER | | ARRAY ANGLE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.0 | 0.0 | | 1.005 | | 75.7 | | 0.0 | ON | 4.19D 00 | | −77.1 | | 80.5 | | 87.9 | | 20.2 | ON | 0.0 |
| 4 | 1.065 | 1.0 | | 1.004 | | 75.3 | | 0.00 | MAX | 4.19D 00 | | −77.1 | | 80.5 | | 87.9 | | 20.2 | | 0.0 |
| 5 | 8.379 | 7.6 | * | 1.000 | | 72.6 | | 0.03 | | 4.15D 00 | | −77.2 | | 79.6 | | 87.7 | | 20.3 | | 0.0 |
| 4 | 8.428 | 7.7 | | 1.000 | | 72.5 | | 0.03 | MIN | 4.15D 00 | | −77.2 | | 79.5 | | 87.7 | MAX | 20.3 | | 0.7 |
| 4 | 80.338 | 82.2 | | 0.889 | | 52.3 | | 0.24 | OFF | −4.00D-15 | | −60.4 | | 44.8 | | 69.5 | | 20.3 | | 37.7 |
| 6 | 91.933 | 96.6 | | 0.870 | | 51.4 | | 0.28 | MIN | −7.45D-01 | | ***** | | ****** | | ***** | | 0.0 | | 90.0 |
| 7 | 99.677 | 106.6 | | 0.858 | MIN | 51.3 | | 0.31 | | −3.23D-01 | | ***** | | ****** | | ***** | | 0.0 | | 90.0 |
| 5 | 103.587 | 111.8 | | 0.853 | | 51.3 | | 0.32 | ON | −1.33D-15 | | 73.2 | | −3.5 | | 73.3 | | 20.3 | | 43.4 |
| 4 | 136.984 | 156.9 | MIN | 0.830 | | 54.2 | | 0.45 | | 2.39D 00 | | 85.4 | | −80.5 | | 89.2 | | 20.3 | | 46.5 |
| 4 | 159.653 | 186.8 | | 0.840 | | 57.0 | | 0.35 | MAX | 2.93D 00 | | 87.2 | | −133.4 | | 91.9 | | 20.3 | | 45.1 |
| 5 | 165.388 | 194.2 | | 0.846 | | 57.6 | | 0.57 | | 2.90D 00 | MAX | 87.3 | | −154.1 | | 92.4 | | 20.3 | | 44.4 |
| 4 | 220.047 | 259.8 | | 0.930 | | 62.3 | | 0.78 | OFF | −1.75D-14 | | 64.0 | | 108.4 | | 98.0 | | 20.3 | | 30.2 |
| 8 | 234.249 | 275.5 | | 0.952 | | 63.3 | | 0.81 | MIN | −7.08D-01 | | ***** | | ****** | | ***** | | 0.0 | | 90.0 |
| 5 | 248.415 | 290.5 | | 0.973 | | 64.5 | | 0.82 | ON | 2.39D-15 | | −58.5 | | 99.2 | | 94.8 | | 20.3 | | 18.8 |
| 4 | 257.189 | 299.5 | | 0.984 | | 65.3 | MAX | 0.82 | | 6.50D-01 | | −68.1 | | 97.2 | | 92.7 | | 20.3 | | 14.5 |
| 4 | 272.871 | 314.9 | * | 1.000 | | 66.7 | | 0.82 | | 1.74D 00 | | −74.7 | | 93.7 | | 91.0 | | 20.3 | | 0.0 |
| 5 | 315.465 | 353.8 | | 1.019 | | 70.4 | | 0.74 | | 3.17D 00 | MIN | −78.1 | | 84.3 | | 88.8 | | 19.8 | | 0.0 |
| 4 | 316.969 | 355.2 | MAX | 1.019 | | 70.5 | | 0.74 | | 3.49D 00 | | −78.1 | | 84.0 | | 88.8 | MIN | 19.8 | | 0.0 |
| 5 | 325.138 | 362.3 | | 1.018 | | 70.9 | | 0.72 | MAX | 3.53D 00 | | −78.0 | | 82.1 | | 88.4 | | 19.8 | | 0.0 |
| 4 | 335.882 | 371.8 | | 1.016 | MAX | 71.1 | | 0.70 | | 3.15D 00 | | −77.7 | | 79.5 | | 87.8 | | 19.9 | | 0.0 |
| 4 | 356.876 | 390.7 | | 1.006 | | 70.3 | MIN | 0.69 | | 2.54D 00 | | −76.5 | | 73.6 | | 86.2 | | 20.2 | | 0.0 |
| 3 | 366.544 | 399.8 | * | 1.000 | | 69.5 | | 0.59 | | 2.39D 00 | | −75.6 | | 70.3 | | 85.2 | | 20.3 | | 0.0 |
| 6 | 401.007 | 434.9 | | 0.976 | | 65.2 | | 0.75 | OFF | −2.22D-16 | | −66.1 | | 49.0 | | 74.6 | | 20.3 | | 17.8 |
| 6 | 420.432 | 456.6 | | 0.965 | | 62.8 | | 0.80 | MIN | −1.24D 00 | | ***** | | ****** | | ***** | | 0.0 | | 90.0 |
| 5 | 439.995 | 478.9 | | 0.957 | | 61.1 | | 0.84 | ON | −1.42D-14 | | 76.8 | | −23.5 | | 77.9 | | 20.3 | | 23.8 |
| 4 | 461.762 | 503.1 | MIN | 0.953 | | 60.2 | | 0.87 | | 1.52D 00 | | 83.1 | | −60.5 | | 86.6 | | 20.3 | | 24.6 |
| 4 | 467.030 | 508.7 | | 0.954 | MIN | 60.2 | | 0.87 | | 1.31D 00 | | 83.9 | | −67.2 | | 87.6 | | 20.3 | | 24.6 |
| 5 | 476.946 | 518.9 | | 0.955 | | 60.3 | MAX | 0.87 | | 2.27D 00 | | 84.9 | | −78.6 | | 89.0 | | 20.3 | | 24.3 |
| 4 | 503.064 | 544.6 | | 0.962 | | 61.2 | | 0.97 | MAX | 2.79D 00 | | 87.6 | | −115.0 | | 91.0 | | 20.3 | | 22.2 |
| 6 | 509.882 | 551.0 | | 0.965 | | 61.5 | MIN | 0.87 | | 2.75D 00 | | 88.1 | | −133.9 | | 91.3 | | 20.3 | | 21.4 |
| 5 | 518.520 | 559.2 | | 0.969 | | 61.8 | | 0.87 | | 2.51D 00 | MAX | 88.5 | | −172.2 | | 91.5 | | 20.3 | | 20.3 |
| 4 | 529.847 | 570.1 | | 0.974 | | 62.1 | | 0.87 | | 2.26D 00 | | 87.8 | | 139.0 | MAX | 91.6 | | 20.3 | | 18.5 |
| 4 | 544.170 | 584.0 | | 0.980 | MAX | 62.3 | | 0.89 | | 1.53D 00 | | 86.0 | | 111.0 | | 91.4 | | 20.3 | | 16.0 |
| 4 | 568.192 | 608.8 | | 0.992 | | 61.9 | | 0.94 | OFF | −2.00D-15 | | 80.2 | | 89.6 | | 89.9 | | 20.3 | | 10.5 |
| 5 | 588.100 | 630.6 | * | 1.000 | | 61.3 | | 0.97 | | −1.51D 00 | | ***** | | ****** | | ***** | | 0.0 | | 90.0 |
| 6 | 593.002 | 636.1 | | 1.002 | | 61.2 | | 0.98 | MIN | −1.72D 00 | | ***** | | ****** | | ***** | | 0.0 | | 90.0 |
| 5 | 604.245 | 648.5 | | 1.006 | MIN | 61.1 | | 0.99 | | −1.04D 00 | | ***** | | ****** | | ***** | | 0.0 | | 90.0 |
| 5 | 613.892 | 658.9 | | 1.009 | | 61.2 | MAX | 1.00 | | −2.92D-01 | | ***** | | ****** | | ***** | | 0.0 | | 90.0 |
| 6 | 617.788 | 663.0 | | 1.010 | | 61.3 | | 1.00 | ON | 0.0 | | −85.0 | | 48.7 | | 86.7 | | 20.1 | | 0.0 |
| 5 | 633.894 | 679.4 | | 1.013 | | 62.1 | | 0.98 | | 1.10D 00 | | −87.1 | MIN | 42.5 | | 87.9 | | 20.0 | | 0.0 |
| 5 | 651.984 | 696.2 | | 1.015 | | 63.6 | | 0.94 | | 2.04D 00 | MIN | −87.6 | | 48.8 | | 88.4 | | 19.9 | | 0.0 |
| 4 | 658.478 | 701.9 | MAX | 1.015 | | 64.3 | | 0.92 | | 2.28D 00 | | −87.5 | | 52.6 | | 88.5 | MIN | 19.9 | | 0.0 |
| 4 | 668.726 | 710.5 | | 1.014 | | 65.4 | | 0.88 | | 2.56D 00 | | −87.4 | | 57.8 | MAX | 88.6 | | 19.9 | | 0.0 |
| 6 | 683.476 | 722.6 | | 1.013 | | 66.8 | | 0.83 | MAX | 2.71D 00 | | −86.8 | | 62.1 | | 88.5 | | 20.0 | | 0.0 |
| 7 | 692.955 | 730.2 | | 1.011 | | 67.4 | | 0.81 | | 2.55D 00 | | −86.3 | MAX | 62.8 | | 88.3 | | 20.0 | | 0.0 |
| 4 | 704.384 | 739.6 | | 1.009 | MAX | 67.7 | | 0.79 | | 2.41D 00 | | −85.6 | | 61.9 | | 87.9 | | 20.1 | | 0.0 |
| 6 | 711.876 | 745.9 | | 1.007 | | 67.6 | MIN | 0.78 | | 2.15D 00 | | −85.1 | | 60.3 | | 87.6 | | 20.1 | | 0.0 |
| 4 | 743.566 | 775.5 | * | 1.000 | | 64.5 | | 0.85 | | 4.29D-01 | | −82.3 | | 42.9 | | 84.3 | | 20.3 | | 0.0 |
| 4 | 749.621 | 781.9 | | 0.999 | | 63.6 | | 0.87 | OFF | −1.33D-15 | | −81.3 | | 36.3 | | 83.0 | | 20.3 | | 3.8 |
| 6 | 778.265 | 815.8 | | 0.995 | | 59.6 | | 0.99 | MIN | −2.00D 00 | | ***** | | ****** | | ***** | | 0.0 | | 90.0 |
| 5 | 796.948 | 838.7 | MIN | 0.995 | | 58.1 | | 1.03 | | −7.51D-01 | | ***** | | ****** | | ***** | | 0.0 | | 90.0 |
| 6 | 806.967 | 850.3 | | 0.995 | | 57.8 | | 1.04 | ON | −2.22D-16 | | 79.5 | | −68.6 | | 86.2 | | 20.3 | | 8.2 |
| 5 | 809.171 | 852.8 | | 0.995 | MIN | 57.8 | | 1.04 | | 1.57D-01 | | 80.1 | | −70.6 | | 86.7 | | 20.3 | | 8.1 |
| 4 | 810.095 | 853.8 | | 0.995 | | 57.8 | MAX | 1.04 | | 2.22D-01 | | 80.3 | | −71.4 | | 86.9 | | 20.3 | | 8.0 |
| 4 | 857.824 | 896.6 | | 1.000 | | 62.1 | | 0.92 | | 2.29D 00 | | 88.4 | | −116.9 | MAX | 90.7 | | 20.3 | | 2.3 |
| 5 | 863.133 | 900.6 | * | 1.000 | | 62.8 | | 0.90 | | 2.33D 00 | | 89.1 | | −136.6 | | 90.7 | | 20.3 | | 0.0 |
| 4 | 866.463 | 903.1 | | 1.000 | | 63.3 | | 0.89 | MAX | 2.34D 00 | | 89.4 | | −165.0 | | 90.6 | | 20.3 | | 0.0 |
| 5 | 868.262 | 904.4 | | 1.000 | | 63.5 | | 0.88 | | 2.34D 00 | MAX | 89.4 | | 171.9 | | 90.6 | | 20.3 | | 0.0 |
| 6 | 895.587 | 924.9 | | 1.001 | | 65.7 | MIN | 0.82 | | 1.75D 00 | | 86.2 | | 81.6 | | 89.5 | | 20.3 | | 0.0 |
| 5 | 896.651 | 925.8 | MAX | 1.001 | | 65.7 | | 0.83 | | 1.71D 00 | | 86.1 | | 80.8 | | 89.4 | MIN | 20.3 | | 0.0 |
| 4 | 898.104 | 926.9 | | 1.001 | MAX | 65.7 | | 0.83 | | 1.55D 00 | | 85.9 | | 79.8 | | 89.3 | | 20.3 | | 0.0 |
| 5 | 912.500 | 939.1 | | 1.001 | | 65.1 | | 0.85 | ON | 9.35D-01 | | 83.8 | | 69.6 | | 87.8 | | 20.3 | ON | 0.0 |

MISSION SCHEDULE

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    __APRIL_21,_1979__1.258800000_01_G.M.T.__
    _____2443985.0370_00_JULIAN_DATE__          DEPART      EARTH

              X              Y              Z           XDOT          YDOT          ZDOT          RADIUS        LAT.     LONG.

PLANET  -8.6292634D-01  -5.1511908D-01   0.0         4.9631942D-01  -8.6241113D-01  0.0          1.0049824D 00   0.0    -149.165
  S/C   -8.6292634D-01  -5.1511908D-01   0.0         4.9543063D-01  -7.8019927D-01 -1.5018595D-01  1.0049824D 00   0.0    -149.165

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CASE   1      (CONVERGED)                            PERFORMANCE SUMMARY

              OUT OF ECLIPTIC MISSION              FINAL INCLINATION = 44.9998      DEG

     LAUNCH VEHICLE IS TITAN III E/CENTAUR                    (COEFFICIENTS =    157238.9500     3480.2038     1753.6965)

        LD = APR 21, 1979, 12.8880 HOURS GMT      AD = OCT 20, 1981,  0.8880 HOURS GMT     FLIGHT TIME =  912.5000 DAYS.
              JULIAN DATE    43985.0370                  JULIAN DATE    44897.5370


                                        ELECTRIC PROPULSION SYSTEM PARAMETERS
                                                                                       EFFICIENCY COEFFICIENTS
  ALPHA A (KG/KW)      ALPHA T (KG/KW)      TANKAGE FACTOR      STRUCTURE FACTOR            B          D (KM/SEC)         E
     15.0000              15.0000              0.0350               0.0                 0.63000          0.0             0.0


                                      ELECTRIC PROPULSION SYSTEM MASS SUMMARY (KG)

                INITIAL        POWER PLANT        PROPELLANT          TANKAGE         STRUCTURE         NET MASS
               3268.5460        620.2500          1821.0797           63.7378            0.0            763.4795


                                      ELECTRIC PROPULSION SYSTEM PERFORMANCE SUMMARY

  P(1 AU) (KW)    P(HSKP) (KW)    P(TARG) (KW)    THR(1 AU) (N)    ACC(1 AU) (M/SEC**2)    ISP (SEC)    EFFIC    CHAR DEG (DAYS)
    20.3500         0.6500          20.3224         0.871551          2.666480D-04         3000.000    0.63000   1.00000000D 30


                                       EXTREME TRAJECTORY AND PERFORMANCE CONDITIONS

  MAX DIST (AU)    MIN DIST (AU)     MAX POWER (KW)    MAX THRUST (N)    BURN TIME (DAYS)    DEGRD TIME (DAYS)    TRAV ANG (DEG)
    1.0189599        0.8296067        20.349999         0.37155141        714.95289            710.01587           948.26191


                                         DEPARTURE AND ARRIVAL CONDITIONS

  DEP DECL (DEG)     PARK INC (DEG)     DEP VINF (M/SEC)    C3 (KM**2/SEC**2)    ARR VINF (M/SEC)    C4 (KM**2/SEC**2)
    -37.8537           36.0000            5099.62849           26.006211              0.0                 0.0
                       AT LIMIT

## B. COMET RENDEZVOUS MISSION

The objective of this mission is to deliver maximum payload to the comet Tempel II, rendezvousing at perihelion of the comet's path in the 1988 apparition. For the case shown, the arrival date is fixed at September 16, 1988; the launch date and launch excess speed are optimized to yield maximum payload for the nominally 4-year class of solutions. The launch vehicle assumed is the Titan III E/Centaur. The electric propulsion system parameters are representative of projections of the SERT III spacecraft. Specifically, the reference power is 8.671 kw, the specific impulse is 2900 seconds, the efficiency is 0.63376 and the specific propulsion system mass (arrays plus power conditioning and thruster subsystem) is 30.285 kg/kw.

This example illustrates the use of the solar array degradation option. This option is invoked by setting the characteristic degradation time TPOWER to a value less than $10^{10}$. In this case, it is set to 7121 days which means that if the arrays were situated at 1 AU and oriented normal to the sun line for this amount of time, the power developed by the array would degrade to 1/e of its initial power output. The input MPOW = 1 forces the arrays to be oriented normal to the sun line throughout the mission. Setting the triggers X30(2) and Y30(2) to 1 results in the optimal adjustment of the trajectory to accomodate the degradation. The complete set of inputs for this case follows and the resultant program output begins on the next page.

```
&MINPUT X1(2)=1.D0,X2(2)=1.D0,X3(2)=1.D0,X4(2)=1.D0,X5(2)=1.D0
X6(2)=1.D0,X11(2)=1.D0,X13(2)=1.D0,X15(2)=1.D0,X7=1.D0
Y1(2)=1.D0,Y2(2)=1.D0,Y3(2)=1.D0,Y4(2)=1.D0,Y5(2)=1.D0,Y6(2)=1.D0
Y13(2)=1.D0,Y15(2)=1.D0,ALPHAT=15.285D0,MBOOST=15,MTMASS=3
MOPT2=3,MOPT3=43,MYEAR=1988,MONTH=9,MDAY=16,HOUR=17.22D0
X12=2.843928504,BI=.63376D0,DI=0.D0,CTANK=.1D0,Y11=8.671D0,3.D0,1.D-3
TPOWER=7121.D0,MPOW=1,X30(2)=1.D0,Y30(2)=1.D0
 X1= 5.072998588224D 00, X2= 3.350183672126D 00, X3=-2.159808142389D 00
 X4=-2.069314933312D 00, X5= 4.565247741305D 00, X6= 3.173220885503D-01
X11= 1.6479796541151D-04,X13= 6.718039798493D 03,X15=-1.517625284470D 03
 X30=-4.657406222646D-03 &END
```

```
X61 =   0.0                        .   0.0                        .   3.0000000000000000 00.   1.0000000000000000-08,   1.0000000000000000 00.
X62 =   0.0                        .   0.0                        .   3.0000000000000000 00.   1.0000000000000000-08,   1.0000000000000000 00.
X63 =   0.0                        .   0.0                        .   3.0000000000000000 00.   1.0000000000000000-08,   1.0000000000000000 00.
X64 =   0.0                        .   0.0                        .   3.0000000000000000 00.   1.0000000000000000-08,   1.0000000000000000 00.
X65 =   0.0                        .   0.0                        .   3.0000000000000000 00.   1.0000000000000000-08,   1.0000000000000000 00.
X66 =   0.0                        .   0.0                        .   3.0000000000000000 00.   1.0000000000000000-08,   1.0000000000000000 00.
X67 =   0.0                        .   0.0                        .   5.0000000000000000 02.   9.9999999999999990-05,   1.0000000000000000 00.
X68 =   0.0                        .   0.0                        .   5.0000000000000000 01.   9.9999999999999990-07,   1.0000000000000000 00.
X69 =   0.0                        .   0.0                        .   3.0000000000000000 00.   1.0000000000000000-08,   1.0000000000000000 00.
X70 =   0.0                        .   0.0                        .   3.0000000000000000 00.   1.0000000000000000-08,   1.0000000000000000 00.
Y 1 =   0.0                        .   1.0000000000000000 00.   9.9999999999999990-05,
Y 2 =   0.0                        .   1.0000000000000000 00.   9.9999999999999990-05,
Y 3 =   0.0                        .   1.0000000000000000 00.   9.9999999999999990-05,
Y 4 =   0.0                        .   1.0000000000000000 00.   9.9999999999999990-05,
Y 5 =   0.0                        .   1.0000000000000000 00.   9.9999999999999990-05,
Y 6 =   0.0                        .   1.0000000000000000 00.   9.9999999999999990-05,
Y 7 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y 8 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y 9 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y10 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y11 =   8.6710000000000000 00.   3.0000000000000000 00.   9.9999999999999990-04,
Y12 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y13 =   0.0                        .   1.0000000000000000 00.   9.9999999999999990-05,
Y14 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y15 =   0.0                        .   1.0000000000000000 00.   9.9999999999999990-05,
Y16 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y17 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y18 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y19 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y20 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y21 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y22 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y23 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y24 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y25 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y26 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y27 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y28 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y29 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y30 =   0.0                        .   1.0000000000000000 00.   9.9999999999999990-05,
Y31 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y32 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y33 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y34 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y35 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y36 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y37 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y38 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y39 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y40 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y41 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y42 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y43 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y44 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y45 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y46 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y47 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y48 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y49 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y50 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y51 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y52 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y53 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y54 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y55 =   0.0                        .   0.0                        .   9.9999999999999990-05,
Y56 =   0.0                        .   0.0                        .   9.9999999999999990-05,
```

```
Y57 =  0.0                    .    0.0                    .    9.9999999999999990-05.
Y58 =  0.0                    .    0.0                    .    9.9999999999999990-05.
Y59 =  0.0                    .    0.0                    .    9.9999999999999990-05.
Y60 =  0.0                    .    0.0                    .    9.9999999999999990-05.
Y61 =  0.0                    .    0.0                    .    9.9999999999999990-05.
Y62 =  0.0                    .    0.0                    .    9.9999999999999990-05.
Y63 =  0.0                    .    0.0                    .    9.9999999999999990-05.
Y64 =  0.0                    .    0.0                    . :  9.9999999999999990-05.
Y65 =  0.0                    .    0.0                    .    9.9999999999999990-05.
Y66 =  0.0                    .    0.0                    .    9.9999999999999990-05.
Y67 =  0.0                    .    0.0                    .    9.9999999999999990-05.
Y68 =  0.0                    .    0.0                    .    9.9999999999999990-05.
Y69 =  0.0                    .    0.0                    .    9.9999999999999990-05.
Y70 =  0.0                    .    0.0                    .    9.9999999999999990-05.
&OUTPUT
AAI= 0.0                      .AE= 0.0                    .ALPHAA=   15.00000000000000    .ALPHAT=  15.28500000000000    .ALTITU=
0.0                           .AN=   1.500000000000000    .AR=  1.000000000000000    .ASOL= 0.0                    .   0.0
0.0                           .  0.0                    .  0.0                    .B1= 0.6337600000000000    .B1= 0.0                    .B2=
0.0                           .B3= 0.0                    .CNI= 0.0                    .CNIX= 0.0                    .   0.0
0.0                           .  0.0                    .  0.0                    .CSTR= 0.0                    .CTANK= 0.1000000000000000D 00.
CTRET= 0.1111111111111111     .DI= 0.0                    .DWRETR= 0.0                    .DPOW= 0.0                    .ECI=
0.0                           .ECIX= 0.0                    .  0.0                    .  0.0                    .  0.0                    .ECI=
0.0                           .EI= 0.0                    .EMUODD= 0.0                    .EMJODX= 0.0                    .
0.0                           .  0.0                    .  0.0                    .  0.0                    .GAMMAX=  1.000000000000000    .GAP=
0.99999999999999990-04.HOUR=   17.22000000000000    .DMI= 0.0                    .OMIX= 0.0                    .
0.0                           .  0.0                    .  0.0                    .  0.0                    .POWFIX= -1.000000000000000    .
PSIGN=  1.000000000000000    .RADODD=  1.000000000000000    .RADODX= 0.0                    .  0.0                    .
0.0                           .  0.0                    .  0.0                    .RAP=   38.00000000000000    .REVS= 0.0                    .
RPER=  2.000000000000000    .SAI=  1.000000000000000    .SAIX= 0.0                    .  0.0                    .
0.0                           .  0.0                    .  0.0                    .SOI= 0.0                    .SOIX= 0.0                    .
0.0                           .  0.0                    .  0.0                    .  0.0                    .SPIRET=   300.0000000000000    .
STATE=  1.000000000000000    .  0.0                    .  0.0                    .  0.0                    .  1.000000000000000    .
0.0                           .STEP1= 0.3125000000000000D-01.STEP2= 0.1250000000000000    .TCOAST= 0.0                    .
0.0                           .  0.0                    .  0.0                    .  0.0                    .  0.0                    .
0.0                           .  0.0                    .  0.0                    .  0.0                    .  0.0                    .
0.0                           .  0.0                    .  0.0                    .  0.0                    .  0.0                    .
0.0                           .  0.0                    .  0.0                    .  0.0                    .TDV= -1.000000000000000    .TGO=
-1.000000000000000    .THRET=   400.0000000000000    .TOFF= -1.000000000000000    .  -1.000000000000000    .  -1.000000000000000    .
-1.000000000000000    .  -1.000000000000000    .  -1.000000000000000    .  -1.000000000000000    .  -1.000000000000000    .
-1.000000000000000    .  -1.000000000000000    .  -1.000000000000000    .  -1.000000000000000    .  -1.000000000000000    .
-1.000000000000000    .  -1.000000000000000    .  -1.000000000000000    .  -1.000000000000000    .  -1.000000000000000    .
-1.000000000000000    .  -1.000000000000000    .TPI= 0.0                    .TPIX= 0.0                    .  0.0                    .
0.0                           .  0.0                    .  0.0                    .TPOWER=   7121.000000000000    .TSCALE=
1.000000000000000    .T2=   50.00000000000000    .  100.0000000000000    .  150.0000000000000    .  200.0000000000000    .
250.0000000000000    .  300.0000000000000    .  350.0000000000000    .  400.0000000000000    .  450.0000000000000    .
500.0000000000000    .XANG1= 0.0                    .XANG2=   32.50000000000000    .XSWING= 0.0                    .
0.0                           .  0.0                    .  0.0                    .  0.0                    .  0.0                    .
0.0                           .  0.0                    .  0.0                    .  0.0                    .  0.0                    .
0.0                           .  0.0                    .  0.0                    .  0.0                    .  0.0                    .
0.0                           .  0.0                    .  0.0                    .  0.0                    .  0.0                    .
0.0                           .  0.0                    .  0.0                    .  0.0                    .  0.0                    .
0.0                           .  0.0                    .  0.0                    .  0.0                    .  0.0                    .
0.0                           .  0.0                    .  0.0                    .  1.000001500000000    .X0=  1.000000000000000    .
0.0                           .  0.0                    .  0.0                    .  1.000001500000000    .  0.0                    .
0.0                           .IBAL=           0.INTPR=          0.IOUT=          0.IRK=          1.IRL=          1.IROT=          0.ISPIN=
          0.ITF=          3.ITPRNT=          0.JPP=          0.JPRINT=          0.JT=          0.KPART=          0.LAUNCH=
          0.LOADX=          0.MAXHAM=          5.MBOOST=         15.MDAY=         16.MODE=          4.MONTH=          9.MOPT=
          0.MOPTX=          0.          0.          0.          0.          0.          0.MOPT2=          3.MOPT3=         43.MOPT4=          0.
          0.          0.          0.          0.          0.          0.          0.MPOW=          1.
MPRINT=          0.MPUNCH=          0.MREAD=          0.MSWING=          0.          0.          0.          0.          0.
          0.          0.          0.          0.          0.MTMASS=          3.MUPDAT=          1.MYEAR=       1988.NDIST=
          3.NHUNG=         25.NORMAL=          0.NPERF=          0.NPRINT=          7.NSET=          0.          0.       300.
          0.NSWING=        300.NSWPAR=          0.NTAPE=         17
&END
```

CASE 1                                                              ITERATOR PARAMETERS


INDEPENDENT VARIABLES

| NO. | INDEX | VALUE | STEP LIMIT | PERTURBATION | WEIGHT |
|---|---|---|---|---|---|
| 1 | 1 | 5.0729985882240000D 00 | 3.00000C00000000000D 00 | 1.0000000000000000D-08 | 1.0000000000000000D 00 |
| 2 | 2 | 3.3501836721260000D 00 | 3.0000000000000000D 00 | 1.0000000000000000D-08 | 1.0000000C000000000D 00 |
| 3 | 3 | -2.1598081423890000D 00 | 3.0000000000000000D 00 | 1.0000000000000000D-08 | 1.0000000000000000D 00 |
| 4 | 4 | -2.0693149333120000D 00 | 3.0000000000000000D 00 | 1.0000000000000000D-08 | 1.0000000000000000D 00 |
| 5 | 5 | 4.5652477413050000D 00 | 3.0000000000000000D 00 | 1.0000000000000000D-08 | 1.0000000000000000D 00 |
| 6 | 6 | 3.3173220885030000D-01 | 3.0000000000000000D 00 | 1.0000000000000000D-08 | 1.0000000000000000D 00 |
| 7 | 11 | 1.6479796541510000D-04 | 9.9999999999999990D-04 | 1.0000000000000000D-11 | 1.0000000000000000D 00 |
| 8 | 13 | 6.7180397984929990D 03 | 5.0000000000000000D 02 | 9.9999999999999990D-05 | 1.0000000000000000D 00 |
| 9 | 15 | -1.5176252844700000D 03 | 8.0000000000000000D 00 | 9.9999999999999990D-07 | 1.0000000000000000D 00 |
| 10 | 30 | -4.6574062226459990D-03 | 1.0000000000000000D 01 | 9.9999999999999990D-05 | 1.0000000000000000D 00 |


DEPENDENT VARIABLES

| NO. | INDEX | VALUE | TOLERANCE |
|---|---|---|---|
| 1 | 1 | 0.0 | 9.9999999999999990D-05 |
| 2 | 2 | 0.0 | 9.9999999999999990D-05 |
| 3 | 3 | 0.0 | 9.9999999999999990D-05 |
| 4 | 4 | 0.0 | 9.9999999999999990D-05 |
| 5 | 5 | 0.0 | 9.9999999999999990D-05 |
| 6 | 6 | 0.0 | 9.9999999999999990D-05 |
| 7 | 11 | 8.6710000000000000D 00 | 9.9999999999999990D-04 |
| 8 | 13 | 0.0 | 9.9999999999999990D-05 |
| 9 | 15 | 0.0 | 9.9999999999999990D-05 |
| 10 | 30 | 0.0 | 9.9999999999999990D-05 |

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------------------------------------------------------------------------------------------------------------------------
---------- NOMINAL TRAJECTORY  1 (TOTAL    1) ---------- INHIBITOR IS    5.8208D-11 -------------------------------------
------------------------------------------------------------------------------------------------------------------------
                                           INDEPENDENT PARAMETERS
   1.PRIMI( 5.0729986D 00)    2.PRIM2( 3.3501837D 00)    3.PRIM3(-2.1598081D 00)   4.PDOTI(-2.0693149D 00)   5.PDOT2( 4.5652477D 00)
   6.PDOT3( 3.3173221D-01)   11.ACCEL( 1.6479797D-04)   13.VINFI( 6.7180398D 03)  15.TIME1(-1.5176253D 03)  30.LDEGR(-4.6574062D-03)
                                           DEPENDENT PARAMETERS
   1.DELTA X(-8.88898D-02)    2.DELTA Y( 3.21013D-01)    3.DELTA Z(-1.56897D-03)   4.DELT XD(-1.14063D-01)   5.DELT YD( 2.32885D-01)
   6.DELT ZD( 5.61628D-03)   11. POWER ( 8.67100D 00)   13.T.VINF1(-4.41645D-02)  15.T.TIME1( 3.36196D-06)  30.T.DEGRD( 2.32504D-03)
THRUST SWITCHING TIMES (DAYS)          0.0        ON     1517.625   ON
                                           ELECTRIC PROPULSION PARAMETERS
      POWER                 EFFICIENCY            PROP TIME              J              PROP TIME RATIO          AVE ACCEL
    8.6710000109           0.6337600000       1517.6252844700       1.0915980627         1.0000000000          0.0001829860
                                           MASS COMPONENT BREAKDOWN
      INITIAL               PROPULSION           PROPELLANT           TANKAGE            STRUCTURE               PAYLOAD
   2345.0574592971        262.6012353301       443.0100468725       44.3010046873         0.0               1595.1451724072


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---------- NOMINAL TRAJECTORY  2 (TOTAL    6) ---------- INHIBITOR IS    5.9605D-08 -------------------------------------
------------------------------------------------------------------------------------------------------------------------
                                           INDEPENDENT PARAMETERS
   1.PRIMI( 5.3132693D 00)    2.PRIM2( 3.3270277D 00)    3.PRIM3(-2.1717152D 00)   4.PDOTI(-2.0698180D 00)   5.PDOT2( 4.7839810D 00)
   6.PDOT3( 3.1881327D-01)   11.ACCEL( 1.6287355D-04)   13.VINFI( 6.6779946D 03)  15.TIME1(-1.5192051D 03)  30.LDEGR(-2.8739127D-03)
                                           DEPENDENT PARAMETERS
   1.DELTA X( 2.52805D-01)    2.DELTA Y( 3.10551D-02)    3.DELTA Z(-3.77541D-02)   4.DELT XD(-4.17647D-02)   5.DELT YD(-1.357670-03)
   6.DELT ZD( 4.36855D-02)   11. POWER ( 8.659520 00)   13.T.VINF1(-7.25369D-02)  15.T.TIME1( 4.72439D-03)  30.T.DEGRD( 3.86791D-03)
THRUST SWITCHING TIMES (DAYS)          0.0        ON     1519.205   ON
                                           ELECTRIC PROPULSION PARAMETERS
      POWER                 EFFICIENCY            PROP TIME              J              PROP TIME RATIO          AVE ACCEL
    8.6595241412           0.6337600000       1519.2050826052       1.0241766936         1.0000000000          0.0001799814
                                           MASS COMPONENT BREAKDOWN
      INITIAL               PROPULSION           PROPELLANT           TANKAGE            STRUCTURE               PAYLOAD
   2369.6249929452        262.2536886154       429.0728049390       42.9072804939         0.0               1635.3912188969


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---------- NOMINAL TRAJECTORY  3 (TOTAL   16) ---------- INHIBITOR IS    3.9063D-03 -------------------------------------
------------------------------------------------------------------------------------------------------------------------
                                           INDEPENDENT PARAMETERS
   1.PRIMI( 5.3133875D 00)    2.PRIM2( 3.3268842D 00)    3.PRIM3(-2.1717072D 00)   4.PDOTI(-2.0695322D 00)   5.PDOT2( 4.7840736D 00)
   6.PDOT3( 3.1878921D-01)   11.ACCEL( 1.6099008D-04)   13.VINFI( 6.7247596D 03)  15.TIME1(-1.5170481D 03)  30.LDEGR(-3.1763748D-03)
                                           DEPENDENT PARAMETERS
   1.DELTA X(-7.41178D-04)    2.DELTA Y( 8.36556D-02)    3.DELTA Z(-1.09468D-02)   4.DELT XD(-5.153640-02)   5.DELT YD( 4.91521D-02)
   6.DELT ZD( 8.26291D-03)   11. POWER ( 8.45577D 00)   13.T.VINF1(-2.37939D-02)  15.T.TIME1( 1.66400D-03)  30.T.DEGRD( 1.44320D-03)
THRUST SWITCHING TIMES (DAYS)          0.0        ON     1206.867   OFF    1375.891   ON     1519.048   ON
                                           ELECTRIC PROPULSION PARAMETERS
      POWER                 EFFICIENCY            PROP TIME              J              PROP TIME RATIO          AVE ACCEL
    8.4557672000           0.6337600000       1350.0244116041       0.8691215491         0.8867305043          0.0001756068
                                           MASS COMPONENT BREAKDOWN
      INITIAL               PROPULSION           PROPELLANT           TANKAGE            STRUCTURE               PAYLOAD
   2340.9387961429        256.0829096522       373.4807477293       37.3480747730         0.0               1674.0270639878
```

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---------- NOMINAL TRAJECTORY   4 (TOTAL   19) ---------- INHIBITOR IS   1.5259D-05 -------------
------------------------------------------------------------------------------------------------
                                 INDEPENDENT PARAMETERS
   1.PRIM1( 5.3132020D 00)    2.PRIM2( 3.3269287D 00)    3.PRIM3(-2.1715769D 00)    4.PDOT1(-2.0689020D 00)    5.PDOT2( 4.7827008D 00)
   6.PDOT3( 3.1889725D-01)   11.ACCEL( 1.6258740D-04)   13.VINF1( 6.7131835D 03)   15.TIME1(-1.5191023D 03)   30.LDEGR(-6.1977463D-03)
                                  DEPENDENT PARAMETERS
  '1.DELTA X(-5.60128D-03)    2.DELTA Y(-1.72518D-02)    3.DELTA Z( 2.42312D-04)     4.DELT XD(-1.73773D-03)    5.DELT YD(-1.22757D-02)
   6.DELT ZD( 8.54559D-03)   11. POWER ( 8.56555D 00)   13.T.VINF1(-2.850650-02)   15.T.TIME1( 4.81076D-04)   30.T.DEGRD(-1.46812D-03)
THRUST SWITCHING TIMES (DAYS)          0.0        ON    1236.139  OFF    1372.865  ON    1519.102  ON
                                 ELECTRIC PROPULSION PARAMETERS
      POWER               EFFICIENCY            PROP TIME           J             PROP TIME RATIO          AVE ACCEL
     8.5655498465         0.6337600000      1382.3770869819     0.8952147629       0.9099960737          0.0001776305
                                   MASS COMPONENT BREAKDOWN
      INITIAL             PROPULSION            PROPELLANT        TANKAGE            STRUCTURE            PAYLOAD
   2348.0346249507      259.4076771027      380.8594236109    38.0859423611        0.0              1669.6815818760


------------------------------------------------------------------------------------------------
---------- NOMINAL TRAJECTORY   5 (TOTAL   22) ---------- INHIBITOR IS   5.9605D-08 -------------
------------------------------------------------------------------------------------------------
                                 INDEPENDENT PARAMETERS
   1.PRIM1( 5.2191362D 00)    2.PRIM2( 3.2734061D 00)    3.PRIM3(-2.1659385D 00)    4.PDOT1(-2.0287369D 00)    5.PDOT2( 4.6843639D 00)
   6.PDOT3( 3.0652065D-01)   11.ACCEL( 1.6373773D-04)   13.VINF1( 6.7146376D 03)   15.TIME1(-1.5190635D 03)   30.LDEGR(-7.2061816D-03)
                                  DEPENDENT PARAMETERS
   1.DELTA X( 1.33510D-03)    2.DELTA Y( 2.14569D-03)    3.DELTA Z(-2.39479D-03)    4.DELT XD(-3.35654D-03)    5.DELT YD(-1.53897D-03)
   6.DELT ZD( 3.88323D-03)   11. POWER ( 8.62288D 00)   13.T.VINF1(-1.21597D-02)   15.T.TIME1( 4.41532D-04)   30.T.DEGRD(-2.53145D-03)
THRUST SWITCHING TIMES (DAYS)          0.0        ON    1232.409  OFF    1374.451  ON    1519.064  ON
                                 ELECTRIC PROPULSION PARAMETERS
      POWER               EFFICIENCY            PROP TIME           J             PROP TIME RATIO          AVE ACCEL
     8.6228773519         0.6337600000      1377.0217396572     0.9071750874       0.9064938549          0.0001789778
                                   MASS COMPONENT BREAKDOWN
      INITIAL             PROPULSION            PROPELLANT        TANKAGE            STRUCTURE            PAYLOAD
   2347.1431552637      261.1438406008      382.7034428903    38.2703442890        0.0              1665.0255274835


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---------- NOMINAL TRAJECTORY   6 (TOTAL   27) ---------- INHIBITOR IS   7.4506D-09 -------------
------------------------------------------------------------------------------------------------
                                 INDEPENDENT PARAMETERS
   1.PRIM1( 5.1599153D 00)    2.PRIM2( 3.2549972D 00)    3'.PRIM3(-2.1596535D 00)    4.PDOT1(-2.0104620D 00)    5.PDOT2( 4.6285800D 00)
   6.PDOT3( 2.8988390D-01)   11.ACCEL( 1.6440323D-04)   13.VINF1( 6.7141174D 03)   15.TIME1(-1.5189516D 03)   30.LDEGR(-5.9051982D-03)
                                  DEPENDENT PARAMETERS
   1.DELTA X( 7.45271D-04)    2.DELTA Y(-6.39267D-04)    3.DELTA Z(-1.51192D-03)    4.DELT XD(-7.33083D-04)    5.DELT YD(-3.71706D-03)
   6.DELT ZD( 1.70128D-03)   11. POWER ( 8.65910D 00)   13.T.VINF1(-3.47048D-03)   15.T.TIME1(-1.05360D-05)   30.T.DEGRD(-1.24976D-03)
THRUST SWITCHING TIMES (DAYS)          0.0        ON    1237.403  OFF    1369.671  ON    1518.952  ON
                                 ELECTRIC PROPULSION PARAMETERS
      POWER               EFFICIENCY            PROP TIME           J             PROP TIME RATIO          AVE ACCEL
     8.6591006747         0.6337600000      1386.6839462631     0.9231469282       0.9129217404          0.0001799027
                                   MASS COMPONENT BREAKDOWN
      INITIAL             PROPULSION            PROPELLANT        TANKAGE            STRUCTURE            PAYLOAD
   2347.4620903736      262.2408639344      387.0664540193    38.7066454019        0.0              1659.4481270183
```

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--------- NOMINAL TRAJECTORY  7 (TOTAL  32) ---------- INHIBITOR IS   1.4901D-08 ----------------------------------------------
--------------------------------------------------------------------------------

                                    INDEPENDENT PARAMETERS
   1.PRIM1( 5.1336404D 00)    2.PRIM2( 3.2629313D 00)    3.PRIM3(-2.1557714D 00)    4.PDOT1(-2.0141728D 00)    5.PDOT2( 4.6048409D 00)
   6.PDOT3( 2.8387868D-01)   11.ACCEL( 1.6460417D-04)   13.VINF1( 6.7137432D 03)   15.TIME1(-1.5187710D 03)   30.LDEGR(-5.1412997D-03)
                                     DEPENDENT PARAMETERS
   1.DELTA X( 2.359270D-04)    2.DELTA Y(-1.076080D-04)    3.DELTA Z(-5.52100D-04)    4.DELT XD(-3.291420D-04)    5.DELT YD(-3.09067D-03)
   6.DELT ZD( 7.41430D-04)   11. POWER ( 8.67053D 00)   13.T.VINF1(-6.54911D-04)   15.T.TIME1(-2.233810-C4)   30.T.DEGRD(-4.99774D-04)
THRUST SWITCHING TIMES (DAYS)          0.0     ON    1239.035  OFF   1368.048  ON     1518.771  ON
                                   ELECTRIC PROPULSION PARAMETERS
      POWER              EFFICIENCY           PROP TIME              J              PROP TIME RATIO           AVE ACCEL
    8.6705313436        0.6337600000     1389.7585967565        0.9280672161           0.9150547169           0.0001801835
                                   MASS COMPONENT BREAKDOWN
      INITIAL           PROPULSION           PROPELLANT          TANKAGE              STRUCTURE               PAYLOAD
   2347.6914743591     262.5870417409      388.4296679449      38.8429667945            0.0                1657.8317978787


--------------------------------------------------------------------------------
---------- NOMINAL TRAJECTORY  8 (TOTAL  36) ---------- INHIBITOR IS   3.7253D-09 ----------------------------------------------
--------------------------------------------------------------------------------

                                    INDEPENDENT PARAMETERS
   1.PRIM1( 5.1088483D 00)    2.PRIM2( 3.2963260D 00)    3.PRIM3(-2.1550970D 00)    4.PDOT1(-2.0358208D 00)    5.PDOT2( 4.5872536D 00)
   6.PDOT3( 2.9845884D-01)   11.ACCEL( 1.6467645D-04)   13.VINF1( 6.7147767D 03)   15.TIME1(-1.5184032D 03)   30.LDEGR(-4.8228501D-03)
                                     DEPENDENT PARAMETERS
   1.DELTA X( 2.39729D-04)    2.DELTA Y(-1.27285D-04)    3.DELTA Z(-8.13075D-05)    4.DELT XD(-1.093890-04)    5.DELT YD(-1.96172D-03)
   6.DELT ZD( 4.01517D-04)   11. POWER ( 8.67200D 00)   13.T.VINF1(-1.39191D-04)   15.T.TIME1(-1.48701D-04)   30.T.DEGRD(-1.80187D-04)
THRUST SWITCHING TIMES (DAYS)          0.0     ON    1238.824  OFF   1363.853  ON     1518.433  ON
                                   ELECTRIC PROPULSION PARAMETERS
      POWER              EFFICIENCY           PROP TIME              J              PROP TIME RATIO           AVE ACCEL
    8.6719973228        0.6337600000     1393.3738931863        0.9324505011           0.9176574035           0.0001803267
                                   MASS COMPONENT BREAKDOWN
      INITIAL           PROPULSION           PROPELLANT          TANKAGE              STRUCTURE               PAYLOAD
   2347.0578738041     262.6314389198      389.7150553728      38.9715055373            0.0                1655.7398739742


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---------- NOMINAL TRAJECTORY  9 (TOTAL  39) ----------- INHIBITOR IS   1.1642D-10 -----------------------------------------------
--------------------------------------------------------------------------------

                                    INDEPENDENT PARAMETERS
   1.PRIM1( 5.0760147D 00)    2.PRIM2( 3.3463430D 00)    3.PRIM3(-2.1582755D 00)    4.PDOT1(-2.0671646D 00)    5.PDOT2( 4.5669170D 00)
   6.PDOT3( 3.2898985D-01)   11.ACCEL( 1.6477406D-04)   13.VINF1( 6.7174628D 03)   15.TIME1(-1.5178833D 03)   30.LDEGR(-4.6613107D-03)
                                     DEPENDENT PARAMETERS
   1.DELTA X( 4.84058D-04)    2.DELTA Y(-9.14775D-04)    3.DELTA Z(-1.93914D-05)    4.DELT XD( 2.63154D-04)    5.DELT YD(-7.39846D-04)
   6.DELT ZD( 1.52396D-04)   11. POWER ( 8.67105D 00)   13.T.VINF1(-1.49676D-04)   15.T.TIME1( 9.641580-06)   30.T.DEGRD(-3.70422D-06)
THRUST SWITCHING TIMES (DAYS)          0.0     ON    1237.601  OFF   1356.688  ON     1517.883  ON
                                   ELECTRIC PROPULSION PARAMETERS
      POWER              EFFICIENCY           PROP TIME              J              PROP TIME RATIO           AVE ACCEL
    8.6710499330        0.6337600000     1398.7961204684        0.9390740281           0.9215439260           0.0001805308
                                   MASS COMPONENT BREAKDOWN
      INITIAL           PROPULSION           PROPELLANT          TANKAGE              STRUCTURE               PAYLOAD
   2345.4111595641     262.6027472223      391.5490838753      39.1549083875            0.0                1652.1044200790

THIS CASE IS CONVERGED.

     40 TRAJECTORIES WITHOUT PARTIAL DERIVATIVES AND   9 TRAJECTORIES WITH PARTIAL DERIVATIVES REQUIRED FOR THIS CASE.

CASE 1             SWITCH POINT SUMMARY

| TIME | SEMI-MAJOR AXIS | ECCENTRICITY | INCLINATION | NODE | ARG POS | RMAG | TRAVEL |
|---|---|---|---|---|---|---|---|
| R1 | R2 | R3 | V1 | V2 | V3 | MASS RATIO | THRUST ACC |
| L1 | L2 | L3 | L4 | L5 | L6 | L7 | HAM |
| LG | LC | LPHI | CONE | CLOCK | HMAG | POWER FNCT | SWITCH FNCT |
| PSI | THETA | PHI | LATITUDE | LONGITUDE | FLT PTH ANGLE | VMAG | PROP TIME |
| S | LS | DENSITY | DPOWR | DPOWD | DEGRAD | CHI | CHI REF |

EARTH             START OF TRAJECTORY, THRUST ON

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.0 | 1.88051647D 00 | 4.59968606D-01 | 3.61057023D 00 | 1.19246544D 02 | 1.80000000D 02 | 1.01599843D 00 | 0.0 |
| 4.96384945D-01 | -8.86484515D-01 | 0.0 | 1.03372294D 00 | 6.02045556D-01 | -7.54731520D-02 | 1.00000000D 00 | 2.72282147D-02 |
| 5.07390960D 00 | 3.34883875D 00 | -2.15881492D 00 | -2.06852277D 00 | 4.56573081D 00 | 3.31035699D-01 | 1.00000000D 00 | -1.37300066D-02 |
| 0.0 | 0.0 | 0.0 | 7.63106077D 01 | 6.67251942D 01 | 1.21764260D 00 | 9.79862918D-01 | 5.23836841D 00 |
| -1.59489053D 01 | 9.40953232D 01 | 9.39374288D 01 | 0.0 | -6.07534559D 01 | -9.68272173D-01 | 1.19864013D 00 | 0.0 |
| 0.0 | -4.65592672D-03 | 9.68754933D-01 | -1.24543143D 00 | 6.53083836D-01 | 1.00000000D 00 | 0.0 | 0.0 |

SWITCH THRUST OFF

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1.23683102D 03 | 2.67049672D 00 | 4.90630378D-01 | 1.08825737D 01 | 1.25632040D 02 | 6.67674540D 01 | 2.73670624D 00 | 2.52946051D 02 |
| -2.63611211D 00 | -5.61296528D-01 | 4.74784359D-01 | 3.96566436D-01 | -4.46020316D-01 | -1.20115403D-02 | 8.71352371D-01 | 6.08287311D-03 |
| 3.75307033D-01 | -1.41086288D 00 | 7.03135538D-01 | 1.92992332D-01 | 1.80125840D-01 | -9.35853695D-01 | 1.77017914D 00 | -1.37301267D-02 |
| -1.95211637D 01 | -1.88467069D-01 | 0.0 | 8.09210446D 01 | 1.30145263D 02 | 1.42395914D 00 | 1.90743054D-01 | -1.27051147D-14 |
| 2.14624934D 01 | 8.81060683D 01 | 8.82374416D 01 | 9.99065272D 01 | -1.67979755D 02 | -2.93507184D 01 | 5.96945006D-01 | 1.23683102D 03 |
| 1.97788487D 02 | -2.27625848D-04 | 1.33519174D-01 | -1.27813690D-01 | 1.30988114D 00 | 9.72606808D-01 | 9.00000000D 01 | 9.00000000D 01 |

SWITCH THRUST ON

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1.35715295D 03 | 2.67049672D 00 | 4.90630378D-01 | 1.08825737D 01 | 1.25632040D 02 | 9.63835672D 01 | 2.06764574D 00 | 2.82562264D 02 |
| -1.50614591D 00 | -1.36241789D 00 | 3.87944452D-01 | 7.10632057D-01 | -2.85511823D-01 | -7.90536006D-02 | 8.71352371D-01 | 1.00425665D-02 |
| 7.14174926D-01 | -8.62338171D-01 | -1.17179606D 00 | 1.30527923D-01 | 3.72514782D-01 | -8.54746384D-01 | 1.77017914D 00 | -1.37301267D-02 |
| -1.95211637D 01 | -1.88467069D-01 | 0.0 | 7.29375879D 01 | 5.70636244D 01 | 1.42395914D 00 | 3.14908724D-01 | -8.23993651D-17 |
| -4.44996537D 01 | 9.85505580D 01 | 9.60875600D 01 | 1.08142825D 01 | -1.37868379D 02 | -2.65512448D 01 | 7.69949037D-01 | 1.23683102D 03 |
| 1.97788487D 02 | -2.27625848D-04 | 2.33909434D-01 | -2.64923277D-01 | 1.17089652D 00 | 9.72606808D-01 | 0.0 | 0.0 |

TEMPEL II(1988)             END OF TRAJECTORY, THRUST ON

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1.51785637D 03 | 3.03673004D 00 | 5.44431648D-01 | 1.24316650D 01 | 1.19118131D 02 | 1.91041078D 02 | 1.38343810D 00 | 3.70829354D 02 |
| 8.86771280D-01 | -1.06032284D 00 | -5.70362666D-02 | 7.86262148D-01 | 6.69570707D-01 | -2.23246432D-01 | 8.33184679D-01 | 2.02263078D-02 |
| 6.32371134D-01 | 9.39816712D-01 | -2.18494377D 00 | -4.08075153D-01 | 8.72622840D-01 | 5.18177314D-01 | 1.88473916D 00 | -1.37301441D-02 |
| -2.05246983D 01 | -2.61343285D-01 | 0.0 | 7.95785650D 01 | 2.02254602D 01 | 1.45172008D 00 | 6.06462629D-01 | 8.16486183D-01 |
| -5.11364286D 01 | 9.83736007D 01 | 9.52427968D 01 | -2.36285515D 00 | -5.00935201D 01 | 2.63376380D-04 | 1.05658510D 00 | 1.39753444D 03 |
| 2.59774436D 02 | 2.21148515D-08 | 5.22493074D-01 | -5.79867479D-01 | 9.00064153D-01 | 9.64177329D-01 | 0.0 | 0.0 |

INDEPENDENT PARAMETERS

| | | | | |
|---|---|---|---|---|
| 1.PRIM1( 5.0739096D 00) | 2.PRIM2( 3.3488387D 00) | 3.PRIM3(-2.1588149D 00) | 4.PDOT1(-2.0685228D 00) | 5.PDOT2( 4.5657308D 00) |
| 6.PDOT3( 3.3103570D-01) | 7.LMASS( 1.0000000D 00) | 8. LTAU( 0.0        ) | 9.   ( 0.0        ) | 10.DECLN( 0.0        ) |
| 11.ACCEL( 1.6478510D-04) | 12.V JET( 2.8439285D 04) | 13.VINF1( 6.7177410D 03) | 14.VINF2( 0.0        ) | 15.TIME1(-1.5178564D 03) |
| 16.TIME2( 0.0        ) | 17.IPARK( 0.0        ) | 18.VEL01( 0.0        ) | 19.VELO2( 0.0        ) | 20.VELO3( 0.0        ) |
| 21.THET1( 0.0        ) | 22.THET2( 0.0        ) | 23.THET3( 0.0        ) | 24.THET4( 0.0        ) | 25.THET5( 0.0        ) |
| 26.THET6( 0.0        ) | 27.THET7( 0.0        ) | 28.THET8( 0.0        ) | 29.THET9( 0.0        ) | 30.LDEGR(-4.6559267D-03) |
| 31. PHI1( 0.0        ) | 32. PHI2( 0.0        ) | 33. PHI3( 0.0        ) | 34. PHI4( 0.0        ) | 35. PHI5( 0.0        ) |
| 36. PHI6( 0.0        ) | 37. PHI7( 0.0        ) | 38. PHI8( 0.0        ) | 39. PHI9( 0.0        ) | 40.PHI10( 0.0        ) |
| 41.PR1-A( 0.0        ) | 42.PR2-A( 0.0        ) | 43.PR3-A( 0.0        ) | 44.PD1-A( 0.0        ) | 45.PD2-A( 0.0        ) |
| 46.PD3-A( 0.0        ) | 47.VINFA( 0.0        ) | 48.TIMEA( 0.0        ) | 49.KSAMP( 0.0        ) | 50.KDROP( 0.0        ) |
| 51.PR1-B( 0.0        ) | 52.PR2-B( 0.0        ) | 53.PR3-B( 0.0        ) | 54.PD1-B( 0.0        ) | 55.PD2-B( 0.0        ) |
| 56.PD3-B( 0.0        ) | 57.VINFB( 0.0        ) | 58.TIME3( 0.0        ) | 59.KSAMP( 0.0        ) | 60.KDROP( 0.0        ) |
| 61.PR1-C( 0.0        ) | 62.PR2-C( 0.0        ) | 63.PR3-C( 0.0        ) | 64.PD1-C( 0.0        ) | 65.PD2-C( 0.0        ) |
| 66.PD3-C( 0.0        ) | 67.VINFC( 0.0        ) | 68.TIMEC( 0.0        ) | 69.KSAMP( 0.0        ) | 70.KDROP( 0.0        ) |

DEPENDENT PARAMETERS

| | | | | |
|---|---|---|---|---|
| 1.DELTA X( 4.65245D-06) | 2.DELTA Y(-8.98292D-06) | 3.DELTA Z(-6.49573D-07) | 4.DELT X0( 2.39851D-06) | 5.DELT Y0(-6.47139D-06) |
| 6.DELT Z0( 1.01292D-06) | 7.   ( 0.0        ) | 8.   ( 0.0        ) | 9.   ( 0.0        ) | 10.   ( 0.0        ) |
| 11. POWER ( 8.67100D 00) | 12.   ( 0.0        ) | 13.T.VINF1(-1.06427D-06) | 14.   ( 0.0        ) | 15.T.TIME1( 7.73449D-08) |
| 16.   ( 0.0        ) | 17.   ( 0.0        ) | 18.   ( 0.0        ) | 19.   ( 0.0        ) | 20.   ( 0.0        ) |
| 21.   ( 0.0        ) | 22.   ( 0.0        ) | 23.   ( 0.0        ) | 24.   ( 0.0        ) | 25.   ( 0.0        ) |
| 26.   ( 0.0        ) | 27.   ( 0.0        ) | 28.   ( 0.0        ) | 29.   ( 0.0        ) | 30.T.DEGRD( 2.21149D-08) |
| 31.   ( 0.0        ) | 32.   ( 0.0        ) | 33.   ( 0.0        ) | 34.   ( 0.0        ) | 35.   ( 0.0        ) |
| 36.   ( 0.0        ) | 37.   ( 0.0        ) | 38.   ( 0.0        ) | 39.   ( 0.0        ) | 40.   ( 0.0        ) |
| 41.   ( 0.0        ) | 42.   ( 0.0        ) | 43.   ( 0.0        ) | 44.   ( 0.0        ) | 45.   ( 0.0        ) |
| 46.   ( 0.0        ) | 47.   ( 0.0        ) | 48.   ( 0.0        ) | 49.   ( 0.0        ) | 50.   ( 0.0        ) |
| 51.   ( 0.0        ) | 52.   ( 0.0        ) | 53.   ( 0.0        ) | 54.   ( 0.0        ) | 55.   ( 0.0        ) |
| 56.   ( 0.0        ) | 57.   ( 0.0        ) | 58.   ( 0.0        ) | 59.   ( 0.0        ) | 60.   ( 0.0        ) |
| 61.   ( 0.0        ) | 62.   ( 0.0        ) | 63.   ( 0.0        ) | 64.   ( 0.0        ) | 65.   ( 0.0        ) |
| 66.   ( 0.0        ) | 67.   ( 0.0        ) | 68.   ( 0.0        ) | 69.   ( 0.0        ) | 70.   ( 0.0        ) |

THRUST SWITCHING TIMES (DAYS)          0.0    ON    1236.831  OFF    1357.153  ON    1517.856  ON

ELECTRIC PROPULSION PARAMETERS

| POWER | EFFICIENCY | PROP TIME | J | PROP TIME RATIO | AVE ACCEL |
|---|---|---|---|---|---|
| 8.6710000072 | 0.6337600000 | 1397.5344446940 | 0.9382774144 | 0.9207290424 | 0.0001805291 |

MASS COMPONENT BREAKDOWN

| INITIAL | PROPULSION | PROPELLANT | TANKAGE | STRUCTURE | PAYLOAD |
|---|---|---|---|---|---|
| 2345.2405989059 | 262.6012352180 | 391.2220623059 | 39.1222062306 | 0.0 | 1652.2950951515 |

SWITCH-COUNT HISTORY    2.2.4.4.4.4.4.4.4/

204 THRUST COMPUTE STEPS.     7 COAST COMPUTE STEPS

CASE 1                                    EXTREMUM POINTS OF SELECTED FUNCTIONS

| I | TIME | ECLIPTIC LONGITUDE | SOLAR DISTANCE | COMMUNICATION ANGLE | COMMUNICATION DISTANCE | SWITCH FUNCTION | PSI | THETA | PHI | INPUT POWER | ARRAY ANGLE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.0 | 0.0 | 1.016 | 86.1 | 0.0 | ON 5.24D 00 | -15.9 | 94.1 | 93.9 | ON 8.5 | 0.0 |
| 4 | 1.834 | 2.1 | 1.016 | 87.7 | 0.01 | 5.25D 00 | -15.8 | 93.4 | 93.3 | MAX 8.5 | 0.0 |
| 4 | 2.644 | 3.1 | MIN 1.016 | 88.4 | 0.01 | 5.25D 00 | -15.7 | 93.1 | 93.0 | 8.5 | 0.0 |
| 4 | 13.958 | 16.2 | 1.024 | 98.7 | 0.05 | MAX 5.30D 00 | -14.4 | 88.8 | 88.9 | 8.4 | 0.0 |
| 5 | 83.425 | 80.3 | 1.364 | MAX 166.0 | 0.38 | 4.15D 00 | -0.4 | 69.7 | 69.7 | 5.5 | 0.0 |
| 4 | 152.250 | 114.2 | 1.867 | 115.4 | 1.22 | 3.83D 00 | 19.1 | MIN 62.8 | 64.5 | 3.3 | 0.0 |
| 5 | 173.169 | 121.2 | 2.016 | 101.0 | 1.58 | MIN 3.30D 00 | 24.6 | 62.0 | 64.8 | 2.9 | 0.0 |
| 4 | 226.549 | 135.4 | 2.372 | 67.2 | 2.57 | 3.94D 00 | MIN 36.5 | 61.3 | 67.3 | 2.2 | 0.0 |
| 5 | 339.725 | 155.6 | 2.992 | MIN 0.9 | 4.01 | 4.55D 00 | 51.5 | 63.0 | 73.6 | 1.4 | 0.0 |
| 7 | 367.048 | 159.4 | 3.115 | 16.9 | MAX 4.07 | 4.70D 00 | 53.6 | 63.7 | 74.8 | 1.3 | 0.0 |
| 7 | 539.712 | 178.8 | 3.679 | 171.8 | MIN 2.70 | 5.13D 00 | 61.0 | 68.7 | 79.9 | 1.0 | 0.0 |
| 5 | 546.123 | 179.4 | 3.694 | MAX 178.3 | 2.71 | 5.13D 00 | 61.1 | 68.9 | 80.0 | 0.9 | 0.0 |
| 4 | 555.805 | 180.3 | 3.714 | 167.8 | 2.75 | MAX 5.13D 00 | 61.3 | 69.2 | 80.2 | 0.9 | 0.0 |
| 4 | 714.156 | 194.5 | 3.913 | 24.1 | 4.82 | 4.85D 00 | MAX 62.7 | 73.5 | 82.5 | 0.8 | 0.0 |
| 5 | 748.378 | 197.5 | 3.922 | 2.8 | MAX 4.93 | 4.59D 00 | 62.7 | 74.3 | 82.9 | 0.8 | 0.0 |
| 5 | 748.744 | 197.5 | 3.922 | MIN 2.8 | 4.93 | 4.59D 00 | 62.7 | 74.3 | 82.9 | 0.8 | 0.0 |
| 4 | 757.403 | 198.3 | MAX 3.922 | 6.6 | 4.93 | 4.55D 00 | 62.6 | 74.5 | 83.0 | 0.8 | 0.0 |
| 5 | 759.248 | 198.4 | 3.922 | 7.8 | 4.92 | 4.54D 00 | 62.6 | 74.6 | 83.0 | MIN 0.8 | 0.0 |
| 5 | 946.761 | 215.3 | 3.742 | MAX 172.0 | 2.76 | 3.23D 00 | 59.7 | 78.9 | 84.4 | 0.9 | 0.0 |
| 5 | 953.421 | 216.0 | 3.729 | 168.6 | MIN 2.75 | 3.17D 00 | 59.5 | 79.0 | 84.5 | 0.9 | 0.0 |
| 4 | 1131.643 | 236.1 | 3.207 | 17.6 | MAX 4.16 | 1.13D 00 | 47.6 | 83.6 | 85.7 | 1.2 | 0.0 |
| 4 | 1157.452 | 239.7 | 3.103 | MIN 6.7 | 4.10 | 8.55D-01 | 43.7 | 84.5 | 86.1 | 1.3 | 0.0 |
| 4 | 1236.831 | 252.8 | 2.737 | 50.4 | 3.25 | OFF -1.27D-14 | 21.5 | 88.1 | 88.2 | 1.7 | 0.0 |
| 5 | 1296.317 | 265.5 | 2.420 | 89.3 | 2.22 | MIN -2.87D-01 | ***** | ****** | ***** | 0.0 | 90.0 |
| 7 | 1357.153 | 282.9 | 2.068 | 134.8 | 1.24 | ON -8.24D-17 | -44.5 | 98.6 | 96.1 | 2.7 | 0.0 |
| 5 | 1394.950 | 297.1 | 1.845 | MAX 158.0 | 0.97 | 3.37D-01 | -54.7 | 102.7 | 97.3 | 3.3 | 0.0 |
| 6 | 1432.834 | 315.0 | 1.636 | 133.2 | MIN 0.76 | 6.55D-01 | -58.8 | 105.2 | 97.8 | 4.0 | 0.0 |
| 5 | 1441.845 | 319.9 | 1.591 | 125.7 | 0.77 | 7.17D-01 | -59.1 | 105.4 | MAX 97.8 | 4.2 | 0.0 |
| 4 | 1444.313 | 321.3 | 1.579 | 123.8 | 0.77 | 7.33D-01 | MAX -59.1 | 105.4 | 97.8 | 4.3 | 0.0 |
| 4 | 1446.468 | 322.6 | 1.569 | 122.1 | 0.77 | 7.45D-01 | MIN -59.1 | 105.4 | 97.8 | 4.3 | 0.0 |
| 4 | 1489.227 | 350.0 | 1.417 | 97.8 | 0.86 | MAX 8.79D-01 | -56.3 | 102.6 | 96.9 | 5.1 | 0.0 |
| 4 | 1517.072 | 370.1 | 1.383 | 89.4 | 0.96 | 8.20D-01 | -51.3 | 98.5 | 95.3 | MAX 5.3 | 0.0 |
| 3 | 1517.855 | 370.7 | MIN 1.383 | 89.2 | 0.96 | 8.15D-01 | -51.1 | 98.4 | 95.2 | 5.3 | 0.0 |
| 4 | 1517.856 | 370.7 | 1.383 | 89.2 | 0.96 | ON 8.15D-01 | -51.1 | 98.4 | 95.2 | ON 5.3 | 0.0 |

MISSION SCHEDULE

-------------------------------------------------------------------------------------------------------------

JULY 21, 1984   2.06670503D 01 G.M.T.
                2445903.361D 00 JULIAN DATE          DEPART       EARTH

|  | X | Y | Z | XDOT | YDOT | ZDOT | RADIUS | LAT. | LONG. |
|---|---|---|---|---|---|---|---|---|---|
| PLANET | 4.9638494D-01 | -8.8648451D-01 | 0.0 | 8.5633575D-01 | 4.8496863D-01 | 0.0 | 1.0159984D 00 | 0.0 | -60.753 |
| S/C | 4.9638494D-01 | -8.8648451D-01 | 0.0 | 1.0337229D 00 | 6.0204556D-01 | -7.5473152D-02 | 1.0159984D 00 | 0.0 | -60.753 |

-------------------------------------------------------------------------------------------------------------

SEPTEMBR 16, 1988   1.72200000D 01 G.M.T.
                    2447421.218D 00 JULIAN DATE      ARRIVE AT TEMPEL II(1988)

|  | X | Y | Z | XDOT | YDOT | ZDOT | RADIUS | LAT. | LONG. |
|---|---|---|---|---|---|---|---|---|---|
| PLANET | 8.8676663D-01 | -1.0603139D 00 | -5.7035617D-02 | 7.8625975D-01 | 6.6957718D-01 | -2.3224744D-01 | 1.3834282D 00 | -2.363 | -50.093 |
| S/C | 8.8677128D-01 | -1.0603228D 00 | -5.7036267D-02 | 7.8626215D-01 | 6.6957071D-01 | -2.3224643D-01 | 1.3834381D 00 | -2.363 | -50.094 |

TWO-BODY TRANSFER ANGLE BETWEEN     EARTH     AND TEMPEL II(1988)  IS   10.9158 DEGREES.

CASE  1      (CONVERGED)                                    PERFORMANCE SUMMARY


                    EARTH       TO TEMPEL II(1988)  WITH FIXED ARRIVAL EXCESS SPEED


                                    ARRIVAL AT TEMPEL II(1988)  PERIHELION

         LAUNCH VEHICLE IS TITAN III E/CENTAUR                      (COEFFICIENTS =    167238.9500    3480.2038    1753.6965)

         LD = JUL 21, 1984, 20.6671 HOURS GMT      AD = SEP 16, 1988, 17.2200 HOURS GMT     FLIGHT TIME = 1517.8564 DAYS.
                 JULIAN DATE   45903.3611                JULIAN DATE   47421.2175


                                    ELECTRIC PROPULSION SYSTEM PARAMETERS
                                                                                      EFFICIENCY COEFFICIENTS
       ALPHA A (KG/KW)      ALPHA T (KG/KW)      TANKAGE FACTOR    STRUCTURE FACTOR         B           D (KM/SEC)         E
          15.0000             15.2850              0.1000              0.0               0.63376           0.0            0.0


                                    ELECTRIC PROPULSION SYSTEM MASS SUMMARY (KG)

              INITIAL       POWER PLANT       PROPELLANT          TANKAGE        STRUCTURE        NET MASS
             2345.2406       262.6012          391.2221          39.1222          0.0            1652.2951


                                    ELECTRIC PROPULSION SYSTEM PERFORMANCE SUMMARY

       P(1 AU) (KW)    P(HSKP) (KW)    P(TARG) (KW)    THR(1 AU) (N)    ACC(1 AU) (M/SEC**2)    ISP (SEC)    EFFIC      CHAR DEG (DAYS)
          8.6710          0.0             5.2586          0.386461          1.647851D-04         2900.000    0.63376    7.12100000 03
                                                                                                                       CONSTRAINED MAX


                                    EXTREME TRAJECTORY AND PERFORMANCE CONDITIONS

       MAX DIST (AU)    MIN DIST (AU)    MAX POWER (KW)    MAX THRUST (N)    BURN TIME (DAYS)    DEGRD TIME (DAYS)    TRAV ANG (DEG)
        3.9221510        1.0155371        8.498784          0.37878516        1397.53444           259.77444           370.82935


                                    DEPARTURE AND ARRIVAL CONDITIONS

       DEP DECL (DEG)    PARK INC (DEG)    DEP VINF (M/SEC)    C3 (KM**2/SEC**2)    ARR VINF (M/SEC)    C4 (KM**2/SEC**2)
          -5.7634          28.5000           6717.74104           45.128045             0.20776            0.000000

## C. MULTIPLE BALLISTIC SWINGBY MISSION

This computer run demonstrates how the program may be effectively used in the investigation of all-ballistic missions (with electric propulsion absent).

In general, trajectories are forced to be all-ballistic by setting the propulsion-time adjoint variable X8 to a "large" negative number (X8 = - 1.D3) with respect to the mass ratio adjoint variable X7 = 1.D0. These settings (together with the reference thrust acceleration X11 = 1.D-4, jet exhaust speed X12 = 1.D0, and non-zero primer vector components X2 = .1D0 at the launch planet and X42 = .1D0 at the first intermediate-target) guarantee that the electric propulsion thrust switch-function will be maintained negative, yielding ballistic flight at all times. The electric propulsion specific masses ALPHAA and ALPHAT are also set to zero, so that the net spacecraft mass equals the launch vehicle payload.

The particular ballistic mission simulation demonstrated here involves a March 6, 1985 launch of a 1,635 kg payload by an Atlas/Centaur launch vehicle (using the launch vehicle selection default-value of MBOOST = 0; actually, changing MBOOST alters the payload mass computation but not the $C_3$ or the trajectory).

The primary target is the Earth, specified by MOPT3 = 3, and there is one intermediate target, the comet Giacobini-Zinner, specified by MOPTX = 41. The launch occurs fifteen days before (X15 = - 15.D0) the reference date (MYEAR = 1985, MONTH = 3, MDAY = 21), and the spacecraft passes Giacobini-Zinner 174.22 days (X48) after the reference date and arrives back at Earth 353 days (X16) after the reference date.

Ten days after passing Giacobini-Zinner a deep-space burn (of 188.9 m/sec) makes possible the re-targeting to Earth. This is accomplished by inputting TDV = 1.00010D5 together with X64(2), X65(2), and X66(2) = 1.D0.

The deep space burn velocity-increment (X64, X65, X66) initial guess is the zero vector, by default. The deep-space burn could just have well occurred before arriving at Giacobini-Zinner (e.g., TDV = 2.00005D5). The iteration sequence consists of a 6x6 hunt, with the independent variables being the initial heliocentric velocity at Earth (X18, X19, X20) and the deep-space burn velocity increment (X64, X65, X66), and the dependent variables being the position targeting at Giacobini-Zinner (Y41, Y42, Y43) and at Earth (Y1, Y2, Y3). The setting MAXHAM = 0 is made to avoid an unwarranted BAD HAMILTONIAN warning message due to the presence of the deep-space burn.

The detailed printout of the iteration sequence is omitted by setting NPRINT = 3 (compared to the default value NPRINT = 7), and three extra lines are added to each print-block by setting MPRINT = 2.

Finally, the multiple ballistic swingby option is invoked by means of MOPT4 = -3, 42, which directs the spacecraft to swingby the primary target (Earth) in such a manner as to re-target to Earth (MOPT4(1) = -3), and then, at the second Earth passage, to again swingby in such a manner as to target to the comet Borrelly (MOPT4(2) = 42). Furthermore, the first Earth swingby is specified as unpowered (MSWING(1) = -1) having T2(1) = 480 days as the initial guess of the Earth-to-Earth transfer time, and the second Earth swingby is specified to be powered (MSWING(2) = -5) with a specified transfer time from Earth to Borrelly (T2(2) = 127 days) and using the input Earth-departure heliocentric velocity initial-guess XSWING(1,2) = .62D0, .91D0, 0.D0. Both swingby iterations converged, and the powered-swingby incremental speed turned out to be -13.7 m/sec, the minus sign denoting a braking burn. The default value of TGO = - 1.D0 resulted in the printout of several pages describing the trajectory segments following the time of primary target passage.

It should be noted that the trajectory simulation would have terminated at the primary target (first Earth encounter) if MOPT4(1) were zero, and would have terminated at the second Earth encounter had MOPT4(2) been zero. The

mission, as simulated, thus consists initially of a comet-flyby, followed by a second comet-flyby making use of a double Earth-swingby to reach the second comet.

The inputs for this computer run are listed below, and the resulting program output is displayed on the following pages.

```
&MINPUT X7=1.D0,X2=.1D0,X42=.1D0,X8=-1.D3,ALPHAA=0.D0,ALPHAT=0.D0
X64(2)=1.D0,X65(2)=1.D0,X66(2)=1.D0,X18(2)=1.D0,X19(2)=1.D0,X20(2)=1.D0
Y1(2)=1.D0,Y2(2)=1.D0,Y3(2)=1.D0,Y41(2)=1.D0,Y42(2)=1.D0,Y43(2)=1.D0
MYEAR=1985,MONTH=3,MDAY=21,MOPT2=3,MOPT3=3,MOPTX=41,X11=1.D-4,X12=1.D0
TDV=1.0001DD5,X15=-15.D0,X16=353.D0,X48=174.22D0
X18=-8.3276D-2,X19=-1.0034D0,X20=-2.0143D-3
T2=480.D0,127.D0,XSWING(1,2)=.62D0,.91D0,0.D0
MOPT4=-3,42,MSWING=-1,-5,MPRINT=2,MAXHAM=0,NPRINT=3 &END
```

```
Y57 =   0.0                .   0.0                .   9.9999999999999990-05.
Y58 =   0.0                .   0.0                .   9.9999999999999990-05.
Y59 =   0.0                .   0.0                .   9.9999999999999990-05.
Y60 =   0.0                .   0.0                .   9.9999999999999990-05.
Y61 =   0.0                .   0.0                .   9.9999999999999990-05.
Y62 =   0.0                .   0.0                .   9.9999999999999990-05.
Y63 =   0.0                .   0.0                .   9.9999999999999990-05.
Y64 =   0.0                .   0.0                .   9.9999999999999990-05.
Y65 =   0.0                .   0.0                .   9.9999999999999990-05.
Y66 =   0.0                .   0.0                .   9.9999999999999990-05.
Y67 =   0.0                .   0.0                .   9.9999999999999990-05.
Y68 =   0.0                .   0.0                .   9.9999999999999990-05.
Y69 =   0.0                .   0.0                .   9.9999999999999990-05.
Y70 =   0.0                .   0.0                .   9.9999999999999990-05.
$OUTPUT
AAI= 0.0              .AE= 0.0              .ALPHAA= 0.0              .ALPHAT= 0.0              .ALTITU=
 0.0                  .AN=   1.500000000000000    .AR=  1.300000000000000    .ASOL= 0.0              .  0.0
 0.0                  .  0.0                .  0.0                .B1= 0.7600000000000000    .B1= 0.0              .B2=
 0.0                  .B3= 0.0              .CNI= 0.0              .CNIX=   31.87374000000000    .  0.0
 0.0                  .  0.0                .  0.0                .CSTR= 0.0              .CTANK= 0.2999999999999990-01.
CTRET= 0.1111111111111111    .DI=   13.00000000000000    .D4RETR= 0.0              .DPOW= 0.0              .ECI=
 0.0                  .ECIX= 0.7075535000000000    .  0.0                .  0.0                .  0.0
 0.0                  .EI= 0.0              .EMUODD= 0.0              .EMJODX= 0.0              .
 0.0                  .  0.0                .  0.0                .  0.0                .GAMMAX=  1.000000000000000    .GAP=
 0.9999999999999990-04.HOUR=   12.00000000000000    .OMI= 0.0              .OMIX=   195.2073800000000    .
 0.0                  .  0.0                .  0.0                .  0.0                .POWFIX= -1.000000000000000    .
PSIGN=  1.000000000000000    .RADDDD=  1.000000000000000    .RADDDX=  1.000000000000000    .  0.0
 0.0                  .  0.0                .  0.0                .RAP=   38.00000000000000    .REVS= 0.0              .
RPER=  2.000000000000000    .SAI=   1.000000000000000    .SAIX=   3.516014000000000    .  0.0
 0.0                  .  0.0                .  0.0                .SDI= 0.0              .SDIX=   172.4822300000000    .
 0.0                  .  0.0                .  0.0                .  0.0                .SPIRET=   300.0000000000000    .
STATE=  1.000000000000000    .  0.0                .  0.0                .  0.0                .  1.000000000000000    .
 0.0                  .STEP1= 0.3125000000000000-01.STEP2= 0.1250000000000000    .TCOAST= 0.0              .
 0.0                  .  0.0                .  0.0                .  0.0                .  0.0                .
 0.0                  .  0.0                .  0.0                .  0.0                .  0.0                .
 0.0                  .  0.0                .  0.0                .  0.0                .  0.0                .
 0.0                  .  0.0                .  0.0                .  0.0                .TDV=   100010.0000000000    .TGO=
-1.000000000000000    .THRET=   400.0000000000000    .TOFF= -1.000000000000000    . -1.000000000000000    . -1.000000000000000    .
-1.000000000000000    . -1.000000000000000    . -1.000000000000000    . -1.000000000000000    . -1.000000000000000    .
-1.000000000000000    . -1.000000000000000    . -1.000000000000000    . -1.000000000000000    . -1.000000000000000    .
-1.000000000000000    . -1.000000000000000    . -1.000000000000000    . -1.000000000000000    . -1.000000000000000    .
-1.000000000000000    . -1.000000000000000    .TPI= 0.0              .
 0.0                  .  0.0                .  0.0                .TPIX=   168.1958333333332    .
 1.000000000000000    .T2=   480.0000000000000    .  127.0000000000000    .  150.0000000000000    .  200.0000000000000    .
 250.0000000000000    .  300.0000000000000    .  350.0000000000000    .  400.0000000000000    .  450.0000000000000    .
 500.0000000000000    .XANG1= 0.0              .XANG2= 0.0              .XSWING= 0.0              .
 0.0                  .  0.0                .  0.6200000000000000    .  0.9100000000000000    .  0.0                .
 0.0                  .  0.0                .  0.0                .  0.0                .  0.0                .
 0.0                  .  0.0                .  0.0                .  0.0                .  0.0                .
 0.0                  .  0.0                .  0.0                .  0.0                .  0.0                .
 0.0                  .  0.0                .  0.0                .  0.0                .  0.0                .
 0.0                  .  0.0                .  0.0                .  1.000000000000000    .X0=  1.000000000000000    .
 0.0                  .  0.0                .  0.0                .  1.000001500000000    .  0.0                .
 0.0                  .IBAL=       0.INTPR=       0.IOUT=        0.IRK=        1.IRL=        1.IROT=       0.ISPIN=
           0.ITF=       3.ITPRNT=      0.JPP=        0.JPRINT=      0.JT=        0.KPART=      0.LAUNCH=
           0.LOADX=      0.MAXHAM=      0.MBOOST=     0.MDAY=      21.MODE=      4.MONTH=      3.MOPT=
          42.MOPTX=     41.       0.        0.        0.        0.MOPT2=     3.MOPT3=     3.MOPT4=        -3.
          42.        0.        0.        0.        0.        0.        0.        0.MPOW=      0.
MPRINT=         2.MPUNCH=      0.MREAD=      0.MSWING=      -1.      -5.        0.        0.        0.
           0.        0.        0.MTMASS=      0.MUPDAT=      1.MYEAR=   1985.NDIST=
           3.NHUNG=     25.NORMAL=      0.NPERF=      0.NPRINT=      3.NSET=        0.        0.      300.
           0.       300.NSWING=      0.NSWPAR=      1.NTAPE=      17
$END
```

## INDEPENDENT VARIABLES

| NO. | INDEX | VALUE | STEP LIMIT | PERTURBATION | WEIGHT |
|-----|-------|-------|------------|--------------|--------|
| 1 | 18 | -8.3276000000000000D-02 | 1.0000000000000000D 00 | 9.9999999999999990D-05 | 1.0000000000000000D 00 |
| 2 | 19 | -1.0034000000000000D 00 | 1.0000000000000000D 00 | 9.9999999999999990D-05 | 1.0000000000000000D 00 |
| 3 | 20 | -2.0143000000000000D-03 | 1.0000000000000000D 00 | 9.9999999999999990D-05 | 1.0000000000000000D 00 |
| 4 | 64 | 0.0 | 3.0000000000000000D 00 | 1.0000000000000000D-08 | 1.0000000000000000D 00 |
| 5 | 65 | 0.0 | 3.0000000000000000D 00 | 1.0000000000000000D-08 | 1.0000000000000000D 00 |
| 6 | 66 | 0.0 | 3.0000000000000000D 00 | 1.0000000000000000D-08 | 1.0000000000000000D 00 |

## DEPENDENT VARIABLES

| NO. | INDEX | VALUE | TOLERANCE |
|-----|-------|-------|-----------|
| 1 | 1 | 0.0 | 9.9999999999999990D-05 |
| 2 | 2 | 0.0 | 9.9999999999999990D-05 |
| 3 | 3 | 0.0 | 9.9999999999999990D-05 |
| 4 | 41 | 0.0 | 9.9999999999999990D-05 |
| 5 | 42 | 0.0 | 9.9999999999999990D-05 |
| 6 | 43 | 0.0 | 9.9999999999999990D-05 |

THIS CASE IS CONVERGED.

8 TRAJECTORIES WITHOUT PARTIAL DERIVATIVES AND    3 TRAJECTORIES WITH PARTIAL DERIVATIVES REQUIRED FOR THIS CASE.

CASE 1                          SWITCH POINT SUMMARY

| TIME | SEMI-MAJOR AXIS | ECCENTRICITY | INCLINATION | NODE | ARG POS | RMAG | TRAVEL |
|---|---|---|---|---|---|---|---|
| R1 | R2 | R3 | V1 | V2 | V3 | MASS RATIO | THRUST ACC |
| L1 | L2 | L3 | L4 | L5 | L6 | L7 | HAM |
| LG | LC | LPHI | CONE | CLOCK | HMAG | POWER FNCT | SWITCH FNCT |
| PSI | THETA | PHI | LATITUDE | LONGITUDE | FLT PTH ANGLE | VMAG | PROP TIME |
| R1 REL | R2 REL | R3 REL | V1 REL | V2 REL | V3 REL | RMAG REL | VMAG REL |
| S/C NUC MAG | S/C TOT MAG | GEO NUC MAG | GEO TOT MAG | ANG(V,R) | ANG(V,XY) | | |
| R1 REL ECL | R2 REL ECL | R3 REL ECL | V1 REL ECL | V2 REL ECL | V3 REL ECL | RMAG ECL | VMAG ECL |

EARTH                          START OF TRAJECTORY, THRUST OFF

| 0.0 | 9.966431370-01 | 9.87735807D-02 | 1.012293330-01 | 3.45870942D 02 | 1.80000000D 02 | 9.922389820-01 | 0.0 |
| -9.622221040-01 | 2.422123450-01 | 0.0 | -1.481254693-01 | -9.951537530-01 | -1.768923210-03 | 1.000000000 00 | 1.70303186D-02 |
| 0.0 | 1.000000000D-01 | 0.0 | 0.0 | 0.0 | 0.0 | 1.000000000 00 | -2.47940469D-02 |
| 0.0 | 0.0 | 0.0 | 9.673317390 01 | 2.824917620 02 | 9.934383060-01 | 1.009919740 00 | -8.85036241D 04 |
| -9.816716580-02 | -7.58709206D 01 | 7.58709418D 01 | 0.0 | 1.65870942D 02 | -5.66291334D 00 | 1.00611892D 00 | 0.0 |
| -3.495828890 08 | -1.429000980 08 | 3.840250440 07 | 4.084347430 01 | -1.501755770 01 | -1.453723040 01 | 3.796095180 08 | 4.58807963D 01 |
| 1.912533690 01 | 1.89370829D 01 | 1.912533690 01 | 1.893708293 01 | 2.710054390 01 | -1.847240120 01 | | |
| -3.79705824D 07 | 3.398198320 08 | -1.648760240 08 | -2.417045180 01 | -3.993010820 01 | 2.298556570 00 | 3.796095180 08 | 4.58807963D 01 |

GIACOB-ZIN(1985)                 END OF TRAJECTORY SEGMENT 1, THRUST OFF

| 1.892200000D 02 | 9.966431370-01 | 9.87735807D-02 | 1.01229530D-31 | 3.458709420 02 | 2.92569026D 01 | 1.031830110 00 | 2.092569030 02 |
| 9.960727880-01 | 2.692797310-01 | 8.909602210-04 | -1.651043050-01 | 9.52719015D-01 | 1.551112643D-03 | 1.000000000 00 | 1.61945216D-02 |
| 8.905341390-02 | 5.195455710-02 | 2.915005070-04 | 7.030975573-02 | -5.991054940-02 | -1.249993590-04 | 1.000000000 00 | -2.479404690-02 |
| 0.0 | 0.0 | 0.0 | 9.010628970 01 | 7.627306110 01 | 9.934383060-01 | 9.603559020-01 | -9.153409050 04 |
| 9.118137630-02 | 1.513198430 01 | 1.513225260 01 | 4.947351943-02 | 1.512780630 01 | 5.296272890 00 | 9.669205880-01 | 0.0 |
| -1.634932600 01 | -2.387458100 01 | -1.407311070 01 | 6.033225320-01 | -1.392004540 01 | 1.519020970 01 | 3.217683210 01 | 2.060510690 01 |
| -1.698502370 01 | -1.826888580 01 | 1.511060130 01 | 1.339544910 01 | 8.832212590 01 | 4.745281770 01 | | |
| -8.552795700 00 | -3.101268090 01 | 6.417390670-01 | 1.558600063 00 | -3.520454280 00 | 2.024222310 01 | 3.217683210 01 | 2.060510690 01 |

GIACOB-ZIN(1985)                 START OF TRAJECTORY SEGMENT 2, THRUST OFF

| 1.892200000D 02 | 9.966431370-01 | 9.877358070-02 | 1.012295300-01 | 3.458709420 02 | 2.925690260 01 | 1.031830110 00 | 2.092569030 02 |
| 9.960727880-01 | 2.692797310-01 | 8.909602210-04 | -1.651043050-01 | 9.52719015D-01 | 1.561112643D-03 | 1.000000000 00 | 1.619452160-02 |
| 8.905341390-02 | 5.195455710-02 | 2.915005070-04 | 7.030975573-02 | -5.991054940-02 | -1.249993590-04 | 1.000000000 00 | -2.479404690-02 |
| 0.0 | 0.0 | 0.0 | 9.010628970 01 | 7.527306110 01 | 9.934383060-01 | 9.603559020-01 | -9.153409050 04 |
| 9.118137630-02 | 1.513198430 01 | 1.513225260 01 | 4.947351940-02 | 1.512780630 01 | 5.296272890 00 | 9.669205880-01 | 0.0 |
| -1.208744450 07 | 6.818518533 07 | 1.332867580 05 | -9.826659340 00 | -2.696773230 00 | 4.649802060-02 | 6.924841930 07 | 1.018745010 01 |
| 1.573990770 01 | 1.334148520 01 | -1.000000000 30 | -1.000000000 30 | 1.647059360 02 | 2.615128950-01 | | |
| 1.249239290 06 | 6.923702200 07 | 1.332867580 05 | -1.015991260 01 | -7.470970320-01 | 4.649802060-02 | 6.924841930 07 | 1.018745010 01 |

DEEP SPACE BURN     188.9 METERS/SECOND AT    199.22 DAYS

EARTH                          END OF TRAJECTORY, THRUST OFF

| 3.680000000D 02 | 9.986165720-01 | 1.034847080-01 | 1.079255140-01 | 3.486292000 02 | 1.799982650 02 | 9.929569780-01 | 3.627565180 02 |
| -9.734610710-01 | 1.957986300-01 | 5.664450510-08 | -9.543430530-02 | -1.001842980 00 | -1.885530520-03 | 1.000000000 00 | 1.701477440-02 |
| 4.423972260-02 | 5.726471970-01 | 9.086427640-04 | -4.716424170-01 | 9.017742720-02 | -1.065531000-05 | 1.000000000 00 | -2.520507910-02 |
| 0.0 | 0.0 | 0.0 | 9.612970400 01 | 2.827036970 02 | 9.939428060-01 | 1.008997940 00 | -8.855679360 04 |
| -1.648836890-02 | -8.304507040 01 | 8.304507070 01 | 3.268511273-36 | 1.696274650 02 | -5.931020270 00 | 1.006379950 00 | 0.0 |
| 9.370437850 02 | -4.494823190 03 | 8.473961320 00 | -3.551054220 00 | -1.776539290-01 | -5.616036930-02 | 4.591465820 03 | 3.555938830 00 |
| -4.526972090 00 | -7.580248210 00 | -1.000000000 30 | -1.000000000 30 | 1.769965160 02 | -9.049328670-01 | | |
| -3.246200580 01 | 4.591343250 03 | 8.473961320 00 | 3.516379180 00 | -5.259509980-01 | -5.616036930-02 | 4.591465820 03 | 3.555938830 00 |

CASE  1                                        ITERATOR SUMMARY


INDEPENDENT PARAMETERS

```
   1.PRIM1( 0.0            )    2.PRIM2( 1.0000000D-01)    3.PRIM3( 0.0           )    4.PDOT1( 0.0           )    5.PDOT2( 0.0            )
   6.PDOT3( 0.0            )    7.LMASS( 1.0000000D 00)    8. LTAJ(-1.0000000D 03)    9.    ( 0.0           )   10.DECLN( 0.0           )
  11.ACCEL( 1.0000000D-04)   12.V JET( 1.0000000D 00)   13.VINF1( 0.0           )   14.VINF2( 0.0           )   15.TIME1(-1.5000000D 01)
  16.TIME2( 3.5300000D 02)   17.IPARK( 0.0           )   18.VE_31(-1.4812547D-01)   19.VE_32(-9.9515375D-01)   20.VELO3(-1.7689232D-03)
  21.THET1( 0.0            )   22.THET2( 0.0           )   23.THET3( 0.0           )   24.THET4( 0.0           )   25.THET5( 0.0            )
  26.THET6( 0.0            )   27.THET7( 0.0           )   28.THET3( 0.0           )   29.THET9( 0.0           )   30.LDEGR( 0.0            )
  31. PHI1( 0.0            )   32. PHI2( 0.0           )   33. P413( 0.0           )   34. PHI4( 0.0           )   35. PHI5( 0.0            )
  36. PHI6( 0.0            )   37. PHI7( 0.0           )   38. P419( 0.0           )   39. PHI9( 0.0           )   40.PHI10( 0.0            )
  41.PR1-A( 8.9053414D-02)   42.PR2-A( 5.1954557D-02)   43.PR3-A( 2.9150051D-04)   44.PD1-A( 7.0309756D-02)   45.PD2-A(-5.9910549D-02)
  46.PD3-A(-1.2499936D-04)   47.VINFA( 0.0           )   48.TIMEA( 1.7422000D 02)   49.KSAMP( 0.0           )   50.KDROP( 0.0            )
  51.PR1-8( 0.0            )   52.PR2-B( 0.0           )   53.PR3-3( 0.0           )   54.PD1-B( 0.0           )   55.PD2-3( 0.0            )
  56.PD3-8( 0.0            )   57.VINF9( 0.0           )   58.TIMEB( 0.0           )   59.KSAMP( 0.0           )   60.KDROP( 0.0            )
  61.PR1-C( 0.0            )   62.PR2-C( 0.0           )   63.PR3-C( 0.0           )   64.PD1-C( 5.5734329D-03)   65.PD2-C( 3.0309412D-03)
  66.PD3-C( 1.4643332D-04)   67.VINFC( 0.0           )   68.TIMEC( 0.0           )   69.KSAMP( 0.0           )   70.KDROP( 0.0            )
```

DEPENDENT PARAMETERS

```
   1.DELTA X(-2.16993D-07)    2.DELTA Y( 3.06910D-05)    3.DELTA Z( 5.66445D-08)    4.    ( 0.0       )    5.    ( 0.0       )
   6.    ( 0.0        )    7.    ( 0.0       )    8.    ( 0.0       )    9.    ( 0.0       )   10.    ( 0.0       )
  11.    ( 0.0        )   12.    ( 0.0       )   13.    ( 0.0       )   14.    ( 0.0       )   15.    ( 0.0       )
  16.    ( 0.0        )   17.    ( 0.0       )   18.    ( 0.0       )   19.    ( 0.0       )   20.    ( 0.0       )
  21.    ( 0.0        )   22.    ( 0.0       )   23.    ( 0.0       )   24.    ( 0.0       )   25.    ( 0.0       )
  26.    ( 0.0        )   27.    ( 0.0       )   28.    ( 0.0       )   29.    ( 0.0       )   30.    ( 0.0       )
  31.    ( 0.0        )   32.    ( 0.0       )   33.    ( 0.0       )   34.    ( 0.0       )   35.    ( 0.0       )
  36.    ( 0.0        )   37.    ( 0.0       )   38.    ( 0.0       )   39.    ( 0.0       )   40.    ( 0.0       )
  41.DEL X A(-5.71715D-08)   42.DEL Y A(-2.07305D-07)   43.DEL Z A( 4.28973D-09)   44.    ( 0.0       )   45.    ( 0.0       )
  46.    ( 0.0        )   47.    ( 0.0       )   48.    ( 0.0       )   49.    ( 0.0       )   50.    ( 0.0       )
  51.    ( 0.0        )   52.    ( 0.0       )   53.    ( 0.0       )   54.    ( 0.0       )   55.    ( 0.0       )
  56.    ( 0.0        )   57.    ( 0.0       )   58.    ( 0.0       )   59.    ( 0.0       )   60.    ( 0.0       )
  61.    ( 0.0        )   62.    ( 0.0       )   63.    ( 0.0       )   64.    ( 0.0       )   65.    ( 0.0       )
  66.    ( 0.0        )   67.    ( 0.0       )   68.    ( 0.0       )   69.    ( 0.0       )   70.    ( 0.0       )
```

THRUST SWITCHING TIMES (DAYS)        0.0    OFF    189.220 VISIT    199.220 ON    368.000 OFF

ELECTRIC PROPULSION PARAMETERS

| POWER | EFFICIENCY | PROP TIME | J | PROP TIME RATIO | AVE ACCEL |
|---|---|---|---|---|---|
| 18175.6839354431 | 0.0000000045 | 0.0 | 0.0 | 0.0 | 0.0001000000 |

MASS COMPONENT BREAKDOWN

| INITIAL | PROPULSION | PROPELLANT | TANKAGE | STRUCTURE | PAYLOAD |
|---|---|---|---|---|---|
| 1634.7360602603 | 0.0 | 0.0 | 0.0 | 0.0 | 1634.7360602603 |


SWITCH-COUNT HISTORY    ALL 5

    0 THRUST COMPUTE STEPS.    52 COAST COMPUTE STEPS

CASE  1

# EXTREMUM POINTS OF SELECTED FUNCTIONS

| I | TIME | ECLIPTIC LONGITUDE | SOLAR DISTANCE | COMMUNICATION ANGLE | DISTANCE | SWITCH FUNCTION | | PSI | THRUST ANGLES THETA | PHI | INPUT POWER | | ARRAY ANGLE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.0 | 0.0 | 0.992 | 3.4 | 0.0 | OFF | -8.35D 04 | ***** | ****** | ***** | 0.0 | ON | 90.0 |
| 4 | 82.559 | 93.1 MIN | 0.898 | 54.6 | 0.23 | | -8.19D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 5 | 179.513 | 200.2 | 1.016 | 77.6 MAX | 0.47 | | -9.03D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 4 | 189.220 | 209.3 | 1.032 | 79.9 | 0.46 | OFF | -9.15D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| | | | | | | | | | | | 0.0 | | 90.0 |
| 0 | 189.220 | 209.3 | 1.032 | 79.9 | 0.46 | OFF | -9.15D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 4 | 199.220 | 218.3 | 1.047 | 82.5 | 0.45 | OFF | -9.27D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 4 | 267.702 | 275.6 MAX | 1.102 | 106.2 | 0.29 | | -9.72D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 4 | 368.000 | 362.8 | 0.993 | 101.8 | 0.00 | OFF | -8.35D 04 | ***** | ****** | ***** | 0.0 | ON | 90.0 |

CASE  1

# MISSION SCHEDULE

---

MARCH  6, 1985   1.20000000D 01 G.M.T.
2446131.0000 00 JULIAN DATE          DEPART     EARTH

| | X | Y | Z | XDOT | YDOT | ZDOT | RADIUS | LAT. | LONG. |
|---|---|---|---|---|---|---|---|---|---|
| PLANET | -9.6222210D-01 | 2.4221234D-01 | 0.0 | -2.6045355D-01 | -9.7355492D-01 | 0.0 | 9.9223898D-01 | 0.0 | 165.871 |
| S/C | -9.6222210D-01 | 2.4221234D-01 | 0.0 | -1.4812547D-01 | -9.9515375D-01 | -1.7689232D-03 | 9.9223898D-01 | 0.0 | 165.871 |

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SEPTEMBR 11, 1985   1.72800000D 01 G.M.T.
2446320.2200 00 JULIAN DATE          PASS GIACOB-ZIN(1985) AT 20.605 KM/SEC

| | X | Y | Z | XDOT | YDOT | ZDOT | RADIUS | LAT. | LONG. |
|---|---|---|---|---|---|---|---|---|---|
| PLANET | 9.9607285D-01 | 2.6927994D-01 | 8.9095593D-04 | -2.1743291D-01 | 1.0709149D 00 | -6.7835209D-01 | 1.0318302D 00 | 0.049 | 15.128 |
| S/C | 9.9607279D-01 | 2.6927973D-01 | 8.9096022D-04 | -1.6510441D-01 | 9.5271901D-01 | 1.5611264D-03 | 1.0318301D 00 | 0.049 | 15.128 |

TWO-BODY TRANSFER ANGLE BETWEEN     EARTH     AND GIACOB-ZIN(1985) IS   209.2569 DEGREES.

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MARCH  9, 1986   1.20000000D 01 G.M.T.
2446499.0000 00 JULIAN DATE          PASS     EARTH     AT  3.556 KM/SEC

| | X | Y | Z | XDOT | YDOT | ZDOT | RADIUS | LAT. | LONG. |
|---|---|---|---|---|---|---|---|---|---|
| PLANET | -9.7346085D-01 | 1.9576794D-01 | 0.0 | -2.1349335D-01 | -9.8418468D-01 | 0.0 | 9.9295071D-01 | 0.0 | 168.629 |
| S/C | -9.7461070D-01 | 1.9579863D-01 | 5.6644505D-08 | -9.5434335D-02 | -1.0018430D 00 | -1.8355305D-03 | 9.9295698D-01 | 0.000 | 168.627 |

TWO-BODY TRANSFER ANGLE BETWEEN     EARTH     AND     EARTH     IS   2.7583 DEGREES.

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CASE   1      (CONVERGED)                                                PERFORMANCE SUMMARY

                                                            EARTH·      TO   ·   EARTH      FLYBY

                                                    WITH VISITATION OF GIACOB-ZIN(1985)

        LAUNCH VEHICLE IS ATLAS(SLV3X)/CENTAUR                              (COEFFICIENTS =      77360.1300      3652.7918      1653.7180)

            LD = MAR   6, 1985, 12.0000 HOURS GMT      AD = MAR   9, 1986, 12.0000 HOURS GMT      FLIGHT TIME =   368.0000 DAYS.
                       JULIAN DATE    46131.0000                 JULIAN DATE    46499.0000

                                                    ELECTRIC PROPULSION SYSTEM PARAMETERS
                                                                                                    EFFICIENCY COEFFICIENTS
    ALPHA A (KG/KW)        ALPHA T (KG/KW)        TANKAGE FACTOR        STRUCTURE FACTOR             B            D (KM/SEC)           E
        0.0                    0.0                   0.0300                 0.0                   0.76300           13.00000          0.0

                                                    ELECTRIC PROPULSION SYSTEM MASS SUMMARY (KG)

                    INITIAL        POWER PLANT        PROPELLANT             TANKAGE         STRUCTURE          NET MASS
                    1634.7361         0.0                0.0                  0.0              0.0             1634.7361

                                                    ELECTRIC PROPULSION SYSTEM PERFORMANCE SUMMARY

    P(1 AU) (KW)    P(HSKP) (KW)    P(TARG) (KW)    THR(1 AU) (N)    ACC(1 AU) (M/SEC**2)    ISP (SEC)    EFFIC      CHAR DEG (DAYS)
    18175.6839         0.0          18339.2277       0.163474          1.0000000-04           0.102      0.00000    1.00000000 30

                                                    EXTREME TRAJECTORY AND PERFORMANCE CONDITIONS

    MAX DIST (AU)    MIN DIST (AU)    MAX POWER (KW)    MAX THRUST (N)    BURN TIME (DAYS)    DEGRD TIME (DAYS)    TRAV ANG (DEG)
    1.1019581         0.8982011         0.0               0.0               0.0                 0.0                 362.75652

                                                    DEPARTURE AND ARRIVAL CONDITIONS

    DEP DECL (DEG)    PARK INC (DEG)    DEP VINF (M/SEC)    C3 (KM**2/SEC**2)    ARR VINF (M/SEC)    C4 (KM**2/SEC**2)
    -5.1246            28.5000           3407.29049          11.609629            3555.93883          12.644701

SWINGBY CONTINUATION ANALYSIS


THIS CASE IS CONVERGED.

    11 TRAJECTORIES WITHOUT PARTIAL DERIVATIVES AND    4 TRAJECTORIES WITH PARTIAL DERIVATIVES REQUIRED FOR THIS CASE.

                                        EARTH       SWINGBY CONTINUATION TO      EARTH

PASS DIST (RADII)   SPEED (M/SEC)   INCLIN (DEG)   NODE (DEG)   ARG PER (DEG)     LEG TIME (DAYS)   MISSION TIME (DAYS)   ARR VINF (M/SEC)
    60.0441            3837.49        162.1881      185.7729      108.232            527.95               895.95              3557.35


ARRIVAL    VOO =   1.18059057D-01 -1.76583002D-02 -1.88553052D-03     MAG =   1.19387235D-01     (ECLIPTIC REFERENCE SYSTEM)
DEPARTURE  VOO =   1.14058254D-01 -3.52707853D-02  5.00585992D-07     MAG =   1.19387242D-01     (ECLIPTIC REFERENCE SYSTEM)


ARRIVAL    VOO =   9.88875047D-01 -1.47907774D-01 -1.57934011D-02     MAG =   1.00000000D 00     (ECLIPTIC REFERENCE SYSTEM)
DEPARTURE  VOO =   9.55363839D-01 -2.95431779D-01  4.19296052D-05     MAG =   1.00000000D 00     (ECLIPTIC REFERENCE SYSTEM)

HELIOCENTRIC APPROACH ANGLE = 177.0.  DEPART ANGLE = 174.2,  BEND ANGLE =   8.7 DEGREES.
SWINGBY INCLINATION W.R.T. ECLIPTIC =  -6.0 DEGREES.


POWERED SWINGBY INCREMENTAL SPEED =      0.0 METERS/SECOND.   BEND ANGLE =   8.7 DEGREES.  (PLANETOCENTRIC)


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POWERED SWINGBY ANALYSIS ONLY, FOR FIXED SWINGBY LEG FLIGHT TIME   127.0 DAYS.


THIS CASE IS CONVERGED.

     5 TRAJECTORIES WITHOUT PARTIAL DERIVATIVES AND   2 TRAJECTORIES WITH PARTIAL DERIVATIVES REQUIRED FOR THIS CASE.

ARRIVAL    VOO =   1.05096419D-01 -5.67395634D-02 -4.65529663D-07     MAG =   1.19434649D-01     (ECLIPTIC REFERENCE SYSTEM)
DEPARTURE  VOO =   8.32614018D-02  8.24040653D-02 -1.79817708D-02     MAG =   1.18516814D-01     (ECLIPTIC REFERENCE SYSTEM)


ARRIVAL    VOO =   8.79949161D-01 -4.75067862D-01 -3.69777727D-05     MAG =   1.00000000D 00     (ECLIPTIC REFERENCE SYSTEM)
DEPARTURE  VOO =   7.02528184D-01  6.95294303D-01 -1.51723371D-01     MAG =   1.00000000D 00     (ECLIPTIC REFERENCE SYSTEM)

HELIOCENTRIC APPROACH ANGLE =   5.7.  DEPART ANGLE =  78.9,  BEND ANGLE =  73.3 DEGREES.
SWINGBY INCLINATION W.R.T. ECLIPTIC =   9.1 DEGREES.


POWERED SWINGBY INCREMENTAL SPEED =   -13.7 METERS/SECOND.   BEND ANGLE =  73.3 DEGREES.  (PLANETOCENTRIC)


                                        EARTH       SWINGBY CONTINUATION TO  BORRELLY(1987)

PASS DIST (RADII)   SPEED (M/SEC)   INCLIN (DEG)   NODE (DEG)   ARG PER (DEG)     LEG TIME (DAYS)   MISSION TIME (DAYS)   ARR VINF (M/SEC)
     3.3636            7057.96         15.9836       15.8632      263.592            127.00              1022.95             17349.74


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DETAILED PRINT OF POST-SWINGBY TRAJECTORY SEGMENT TO      EARTH

FOR SOLUTION HAVING  60.04 PASSAGE DISTANCE

| TIME | SEMI-MAJOR AXIS | ECCENTRICITY | INCLINATION | NODE | ARG POS | RMAG | TRAVEL |
|------|-----------------|--------------|-------------|------|---------|------|--------|
| R1 | R2 | R3 | V1 | V2 | V3 | MASS RATIO | THRUST ACC |
| L1 | L2 | L3 | L4 | L5 | L6 | L7 | HAM |
| LG | LC | LPHI | CONE | CLOCK | HMAG | POWER FNCT | SWITCH FNCT |
| PSI | THETA | PHI | LATITUDE | LONGITUDE | FLT PTH ANGLE | VMAG | PROP TIME |
| R1 REL | R2 REL | R3 REL | V1 REL | V2 REL | V3 REL | RMAG REL | VMAG REL |
| S/C NUC MAG | S/C TOT MAG | GEO NUC MAG | GEO TOT MAG | ANG(V,R) | ANG(V,XY) | | |
| R1 REL ECL | R2 REL ECL | R3 REL ECL | V1 REL ECL | V2 REL ECL | V3 REL ECL | RMAG ECL | VMAG ECL |

EARTH                                    START OF TRAJECTORY SEGMENT 3, THRUST OFF

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3.68000000D 02 | 1.03625958D 00 | 1.09300439D-01 | 2.86571131D-05 | 1.79999991D 02 | 3.49627474D 02 | 9.92956978D-01 | 3.62756518D 02 |
| -9.73461071D-01 | 1.95798630D-01 | 5.66445051D-08 | -9.94351089D-02 | -1.01945546D 00 | 5.00585992D-07 | 1.00000000D 00 | 1.70147744D-02 |
| 4.42397226D-02 | 5.72647197D-01 | 9.08642764D-04 | -4.71642417D-01 | 9.01774272D-02 | -1.06553100D-05 | 1.00000000D 00 | -2.55037591D-02 |
| 0.0 | 0.0 | 0.0 | 9.61297040D 01 | 2.82703697D 02 | 1.01186946D 00 | 1.00899794D 00 | -3.56615874D 04 |
| 9.06712656D-02 | -8.30450619D 01 | 8.30450707D 01 | 3.26851127D-06 | 1.68627465D 02 | -5.80167143D 00 | 1.02429331D 00 | 0.0 |
| 9.37043785D 02 | -4.49482319D 03 | 8.47396132D 00 | -3.53765537D 00 | 3.60129900D-01 | 1.49099120D-05 | 4.59146582D 03 | 3.55593905D 00 |
| -4.52697209D 00 | -7.58024821D 00 | -1.00000000D 30 | -1.00000000D 30 | 1.74187371D 02 | 2.40238942D-04 | | |
| -3.24620058D 01 | 4.59134325D 03 | 8.47396132D 00 | 3.39721559D 00 | -1.05053740D 00 | 1.49099120D-05 | 4.59146582D 03 | 3.55593905D 00 |

EARTH                                    END OF TRAJECTORY, THRUST OFF

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8.95945897D 02 | 1.03625958D 00 | 1.09300439D-01 | 2.86571131D-05 | 1.79999991D 02 | 1.45934513D 02 | 1.01205077D 00 | 8.80063558D 02 |
| 8.38380643D-01 | -5.66890347D-01 | 1.40795398D-07 | 6.49008911D-01 | 7.68090940D-01 | -4.65529660D-07 | 1.00000000D 00 | 1.66065959D-02 |
| -5.76592725D-01 | -7.09802000D-01 | -8.22036755D-04 | 8.09433294D-01 | -5.48973269D-01 | -5.16342137D-04 | 1.00000000D 00 | -2.55037591D-02 |
| 0.0 | 0.0 | 0.0 | 7.94284059D 01 | 2.60568839D 02 | 1.01186946D 00 | 9.84792437D-01 | -3.58057058D 04 |
| -5.15304272D-02 | -9.50224599D 01 | 9.50224579D 01 | 7.97092623D-06 | -3.40654957D 01 | 6.13109852D 00 | 1.00557260D 00 | 0.0 |
| 3.76962632D 01 | -7.02304520D 00 | 2.10628507D 01 | 3.53975135D 00 | 3.53421754D-01 | -1.38657621D-05 | 4.37490012D 01 | 3.55735106D 00 |
| -1.31587261D 01 | -1.76437918D 01 | -1.00000000D 30 | -1.00000000D 30 | 5.70172444D 00 | -2.23325187D-04 | | |
| 2.72936130D 01 | -2.69330673D 01 | 2.10628507D 01 | 3.13028809D 00 | -1.68998317D 00 | -1.38657621D-05 | 4.37490012D 01 | 3.55735106D 00 |

CASE  1                                              EXTREMUM POINTS OF SELECTED FUNCTIONS

| I | TIME | ECLIPTIC LONGITUDE | | SOLAR DISTANCE | COMMUNICATION ANGLE | | DISTANCE | SWITCH FUNCTION | | PSI | THRUST ANGLES THETA | PHI | INPUT POWER | | ARRAY ANGLE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.0 | 0.0 | | 0.992 | 3.4 | | 0.0 | OFF | -8.85D 04 | ***** | ****** | ***** | 0.0 | ON | 90.0 |
| 4 | 82.559 | 93.1 | MIN | 0.898 | 54.6 | | 0.23 | | -8.19D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 5 | 179.513 | 200.2 | | 1.016 | 77.6 | MAX | 0.47 | | -9.03D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 4 | 189.220 | 209.3 | | 1.032 | 79.9 | | 0.46 | OFF | -9.15D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| | | | | | | | | | | | | | | | |
| 0 | 189.220 | 209.3 | | 1.032 | 79.9 | | 0.46 | OFF | -9.15D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 4 | 199.220 | 218.3 | | 1.047 | 82.5 | | 0.45 | OFF | -9.27D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 4 | 267.702 | 275.6 | MAX | 1.102 | 106.2 | | 0.29 | | -9.72D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 4 | 368.000 | 362.8 | | 0.993 | 101.8 | | 0.00 | OFF | -8.35D 04 | ***** | ****** | ***** | 0.0 | ON | 90.0 |
| | | | | | | | | | | | | | | | |
| 0 | 368.000 | 362.8 | | 0.993 | 101.8 | | 0.00 | OFF | -3.57D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 4 | 368.005 | 362.8 | | 0.993 | 84.2 | MIN | 0.00 | | -3.57D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 4 | 434.075 | 436.2 | MIN | 0.923 | 54.6 | | 0.17 | | -3.52D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 5 | 521.214 | 530.2 | | 1.032 | 83.4 | MAX | 0.34 | | -3.50D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 4 | 626.726 | 616.2 | MAX | 1.150 | 169.8 | | 0.16 | | -3.59D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 9 | 632.049 | 620.2 | | 1.149 | 179.5 | MIN | 0.16 | | -3.59D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 7 | 632.345 | 620.4 | | 1.149 | MAX 180.0 | | 0.16 | | -3.59D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 5 | 742.568 | 712.1 | | 1.012 | 82.8 | MAX | 0.35 | | -3.53D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 4 | 819.377 | 796.2 | MIN | 0.923 | 57.9 | | 0.20 | | -3.52D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 3 | 895.946 | 880.1 | | 1.012 | 92.6 | MIN | 0.00 | | -3.58D 04 | ***** | ****** | ***** | 0.0 | | 90.0 |
| 4 | 895.946 | 880.1 | | 1.012 | 149.5 | | 0.00 | OFF | -3.59D 04 | ***** | ****** | ***** | 0.0 | ON | 90.0 |

__AUGUST_19,_1987__1.07015188D_01_G.M.T.__
_____2447026.946D_00_JULIAN_DATE          PASS     EARTH       AT   3.557 KM/SEC

| | X | Y | Z | XDOT | YDOT | ZDOT | RADIUS | LAT. | LONG. |
|---|---|---|---|---|---|---|---|---|---|
| PLANET | 8.3838046D-01 | -5.6689017D-01 | 0.0 | 5.4391249D-01 | 8.2483050D-01 | 0.0 | 1.0120505D 00 | 0.0 | -34.065 |
| S/C | 8.3838064D-01 | -5.6689035D-01 | 1.4079540D-07 | 6.4900891D-01 | 7.6809094D-01 | -4.6552966D-07 | 1.0120508D 00 | 0.000 | -34.065 |

TWO-BODY TRANSFER ANGLE BETWEEN      EARTH      AND      EARTH      IS  160.0636 DEGREES.

DETAILED PRINT OF POST-SWINGBY TRAJECTORY SEGMENT TO  BORRELLY(1987)

FOR SOLUTION HAVING   3.36 PASSAGE DISTANCE

| TIME | SEMI-MAJOR AXIS | ECCENTRICITY | INCLINATION | NODE | ARG POS | RMAG | TRAVEL |
|------|-----------------|--------------|-------------|------|---------|------|--------|
| R1 | R2 | R3 | V1 | V2 | V3 | MASS RATIO | THRUST ACC |
| L1 | L2 | L3 | L4 | L5 | L6 | L7 | HAM |
| LG | LC | LPHI | CONE | CLOCK | HMAG | POWER FNCT | SWITCH FNCT |
| PSI | THETA | PHI | LATITUDE | LONGITUDE | FLT PTH ANGLE | VMAG | PROP TIME |
| R1 REL | R2 REL | R3 REL | V1 REL | V2 REL | V3 REL | RMAG REL | VMAG REL |
| S/C NUC MAG | S/C TOT MAG | GEO NUC MAG | GEO TOT MAG | ANG(V,R) | ANG(V,XY) | | |
| R1 REL ECL | R2 REL ECL | R3 REL ECL | V1 REL ECL | V2 REL ECL | V3 REL ECL | RMAG ECL | VMAG ECL |

EARTH                                        START OF TRAJECTORY SEGMENT 4, THRUST OFF

```
8.95945897D 02  1.31675896D 00  2.31624927D-01  9.34109222D-01  1.45934993D 02  1.79999511D 02  1.01205077D 00  8.80063558D 02
.8.38380643D-01 -5.66890347D-01  1.40795398D-07  6.27173894D-01  9.07234569D-01 -1.79817708D-02  1.00000000D 00  1.66065959D-02
-5.76592725D-01 -7.09802000D-01 -8.22036755D-04  8.09433294D-01 -5.48973269D-01 -5.16342137D-04  1.00000000D 00  6.85470793D-02
0.0             0.0             0.0             7.94284059D 01  2.60568839D 02  1.11629508D 00  9.84792437D-01 -3.58057058D 04
-9.82025299D-01 -9.50231976D 01  9.50224579D 01  7.97092623D-06 -3.40654957D 01  5.90643552D-01  1.10306165D 00  0.0
-1.69367987D 08 -6.70264746D 07  7.21319150D 07  2.63030952D 01  5.91323267D 00  5.18989117D 00  1.95910895D 08  2.74545826D 01
 1.73856513D 01  1.69804738D 01  1.73856509D 01  1.69804738D 01  1.66528869D 01  1.08965033D 01
-1.19806972D 08 -6.18246515D 07  1.42144577D 08  2.60083123D 01  3.05278047D 00 -8.24635270D 00  1.95910895D 08  2.74545826D 01
```

BORRELLY(1987)                               END OF TRAJECTORY, THRUST OFF

```
1.02294590D 03  1.31675896D 00  2.31624927D-01  9.34109222D-01  1.45934993D 02  2.87810226D 02  1.35864643D 00  9.87874273D 02
3.80201236D-01  1.30419417D 00 -2.10878993D-02 -7.34535522D-01  4.16015951D-01  1.08930260D-03  1.00000000D 00  1.09073500D-02
8.11785347D-01 -4.19648936D-01  4.26549064D-03  2.10373153D-01  4.35492117D-01  5.25235184D-03  1.00000000D 00  6.85470793D-02
0.0             0.0             0.0             1.03022842D 02  2.62522979D 02  1.11629508D 00  6.46819844D-01 -3.89521325D 04
3.76840309D-01 -1.01086943D 02  1.01086701D 02 -8.89338181D-01  7.37474369D 01  1.32703596D 01  8.44164020D-01  0.0
4.86518811D 00 -9.59694915D 00 -2.09227858D 00  4.70047212D 00 -1.13557788D 01 -1.22460387D 01  1.09612553D 01  1.73497439D 01
-1.70193101D 01 -2.00098098D 01  1.48530167D 01  1.42706208D 01  7.42807077D 01 -4.48969591D 01
8.27254589D 00  2.54795529D 00 -6.72473244D 00  4.72217933D 00  3.25534561D 00 -1.63742896D 01  1.09612553D 01  1.73497439D 01
```

CASE 1

EXTREMUM POINTS OF SELECTED FUNCTIONS

| I | TIME | ECLIPTIC LONGITUDE | SOLAR DISTANCE | COMMUNICATION ANGLE | COMMUNICATION DISTANCE | SWITCH FUNCTION | THRUST ANGLES PSI | THRUST ANGLES THETA | THRUST ANGLES PHI | INPUT POWER | ARRAY ANGLE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.0 | 0.0 | 0.992 | 3.4 | 0.0 | OFF -8.85D 04 | ***** | ****** | ***** | 0.0 | ON 90.0 |
| 4 | 82.559 | 93.1 MIN | 0.898 | 54.6 | 0.23 | -8.19D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 5 | 179.513 | 200.2 | 1.016 | 77.6 MAX | 0.47 | -9.03D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 4 | 189.220 | 209.3 | 1.032 | 79.9 | 0.46 | OFF -9.15D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| | | | | | | | | | | | |
| 0 | 189.220 | 209.3 | 1.032 | 79.9 | 0.46 | OFF -9.15D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 4 | 199.220 | 218.3 | 1.047 | 82.5 | 0.45 | OFF -9.27D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 4 | 267.702 | 275.6 MAX | 1.102 | 106.2 | 0.29 | -9.72D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 4 | 368.000 | 362.8 | 0.993 | 101.8 | 0.00 | OFF -8.85D 04 | ***** | ****** | ***** | 0.0 | ON 90.0 |
| | | | | | | | | | | | |
| 0 | 368.000 | 362.8 | 0.993 | 101.8 | 0.00 | OFF -3.57D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 4 | 368.005 | 362.8 | 0.993 | 84.2 MIN | 0.00 | -3.57D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 4 | 434.075 | 436.2 MIN | 0.923 | 54.6 | 0.17 | -3.52D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 5 | 521.214 | 530.2 | 1.032 | 83.4 MAX | 0.34 | -3.53D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 4 | 626.726 | 616.2 MAX | 1.150 | 169.8 | 0.16 | -3.59D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 9 | 632.049 | 620.2 | 1.149 | 179.5 MIN | 0.16 | -3.59D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 7 | 632.345 | 620.4 | 1.149 | 180.0 MAX | 0.16 | -3.59D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 5 | 742.568 | 712.1 | 1.012 | 82.8 MAX | 0.35 | -3.59D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 4 | 819.377 | 796.2 MIN | 0.923 | 57.9 | 0.20 | -3.52D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 3 | 895.946 | 880.1 | 1.012 | 92.6 MIN | 0.00 | -3.58D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 4 | 895.946 | 880.1 | 1.012 | 149.5 | 0.00 | OFF -3.58D 04 | ***** | ****** | ***** | 0.0 | ON 90.0 |
| | | | | | | | | | | | |
| 0 | 895.946 | 880.1 | 1.012 | 149.5 | 0.00 | OFF -3.58D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 7 | 895.946 | 880.1 | 1.012 | 151.1 MIN | 0.00 | -3.58D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 8 | 963.191 | 945.8 | 1.150 | 173.7 MAX | 0.16 | -3.59D 04 | ***** | ****** | ***** | 0.0 | 90.0 |
| 4 | 1022.946 | 987.9 | 1.359 | 125.6 | 0.53 | OFF -3.93D 04 | ***** | ****** | ***** | 0.0 | ON 90.0 |

DECEMBER 24, 1987  1.070151880 01 G.M.T.
               2447153.9460 00 JULIAN DATE

PASS  BORRELLY(1987)  AT 17.350 KM/SEC

| | X | Y | Z | XDOT | YDOT | ZDOT | RADIUS | LAT. | LONG. |
|---|---|---|---|---|---|---|---|---|---|
| PLANET | 3.8020118D-01 | 1.3041942D 00 | -2.1087854D-02 | -8.9307816D-01 | 3.0572085D-01 | 5.5084037D-01 | 1.3586464D 00 | -0.889 | 73.747 |
| S/C | 3.8020124D-01 | 1.3041942D 00 | -2.1087899D-02 | -7.3453552D-01 | 4.1601595D-01 | 1.0893026D-03 | 1.3586464D 00 | -0.889 | 73.747 |

TWO-BODY TRANSFER ANGLE BETWEEN     EARTH     AND  BORRELLY(1987)  IS  267.8768 DEGREES.

# V.  REFERENCES

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